Volume 33 JULY, 1949 Number 7

BULLETIN
of the
American Association *of* Petroleum Geologists

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THE BULLETIN is published by the Association on the 15th of each month.

EDITORIAL AND PUBLICATION OFFICE AND ASSOCIATION HEADQUARTERS, Chestnut-Smith Building, 624 South Cheyenne Avenue, Tulsa, Oklahoma. Post Office, Box 979, Tulsa 1. Cable address: AAPEGOL.

SUBSCRIPTION PRICE to non-members is $15 per year (separate numbers, $1.50), prepaid to addresses in the United States; outside the United States, $15.40.

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Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1918.

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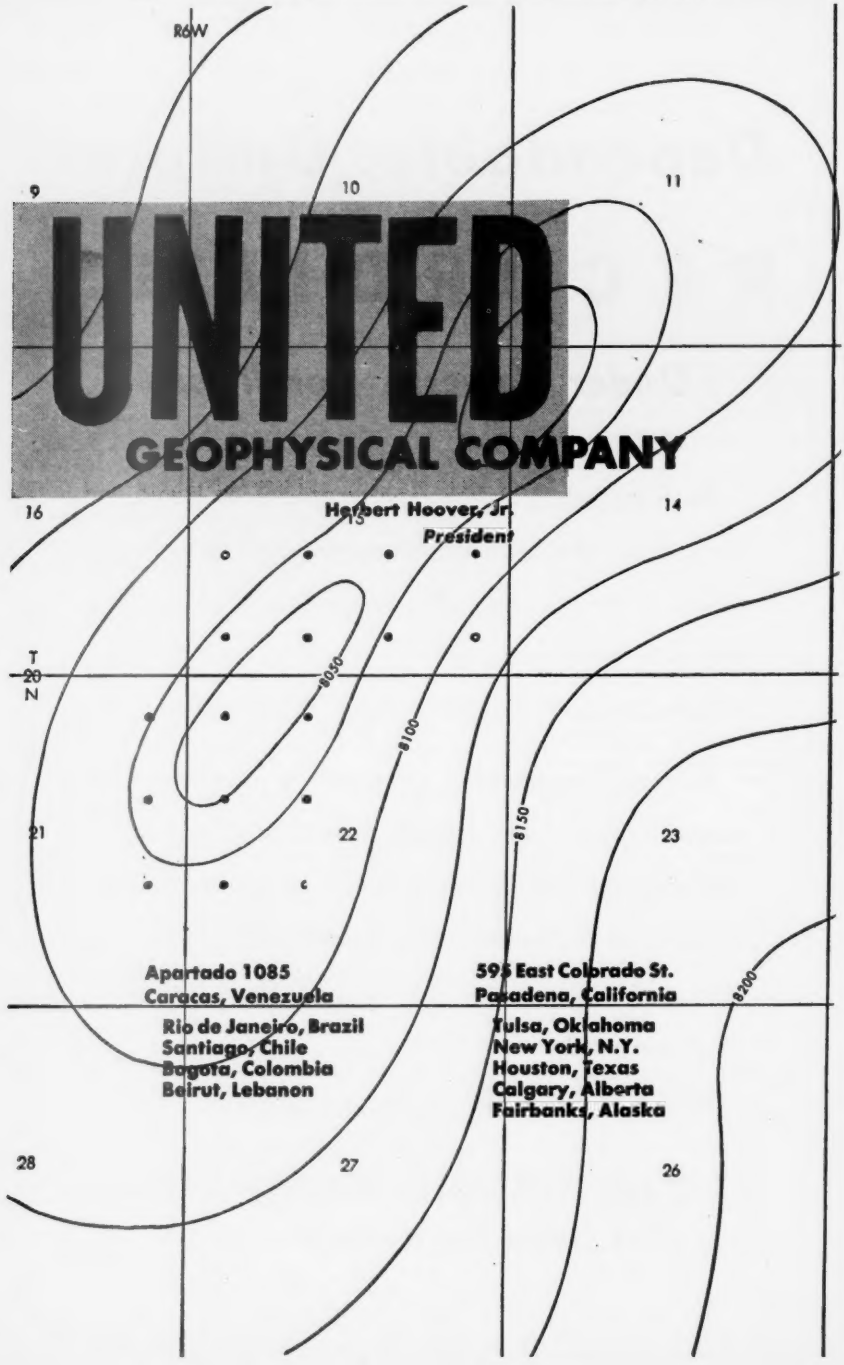
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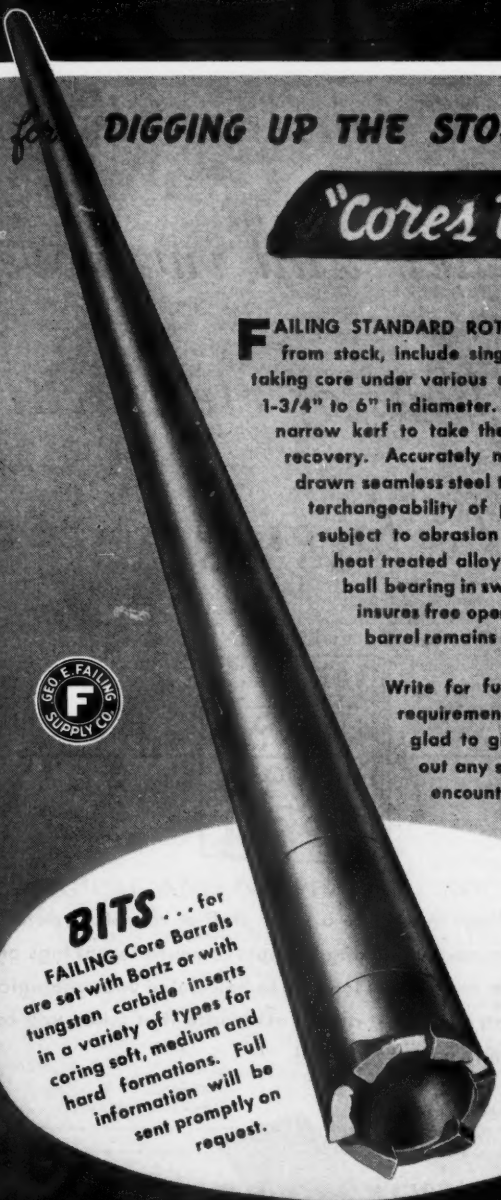

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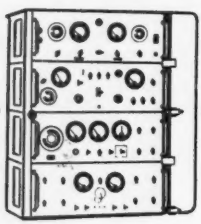

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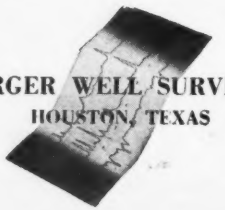

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Volume 33 Number 7

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of the
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JULY, 1949

GEOLOGICAL INTERPRETATION OF EXPLORATORY WELLS[1]

PAUL WEAVER[2]
Houston, Texas

To the authors of papers which have appeared in the *Bulletin* during the past year, and of papers which are being presented at this gathering—the thirty-fourth annual meeting of the American Association of Petroleum Geologists—the members owe a great debt, because these authors are maintaining the unique prestige which the Association enjoys because of the technical importance of their publications in the field of petroleum geology.

Recognition is also due from our members to those who have solicited these authors for their papers, and to those who have aided them in preparing and editing, including especially the program committee for this annual meeting, the research committee, the editor and his regional contributors, and the headquarters staff.

Each of the members who reads these papers finds guidance in some of his own problems of interpretation of the data which he is collecting, and is kept abreast of new mapping and new technique widely diversified topically and geographically, so that it may seem the archive of petroleum geology is an accumulative assemblage of data, much of which is not primarily geologic, and the author proposes that there be an orientation of the petroleum geologist's traverses through these voluminous data so that the geologically significant outcrops of these multifarious landscapes be visited, mapped, and interpreted.

All of our members—old and young—are engaged in the search for more oil and gas, and I propose to discuss one part of our activity, namely, that which is concerned with the geological interpretation of exploratory wells, and particularly the new-field wildcats. I shall omit reference to the geophysical and geological techniques which are used to locate a well-site, and shall restrict the discussion to the geological interpretation of logs of various kinds and of the samples taken

[1] Presidential address, 34th annual meeting, St. Louis, March 15, 1949. Manuscript received, June 14, 1949.

[2] Chief geophysicist, Gulf Oil Corporation.

while the exploratory well is drilling. I shall particularly stress the study of the unsuccessful wildcats, not because they are more important *per se*, but because they present our most perplexing problems: (1) Have they supplied information which confirms the prospects on which they were drilled, and (2) In which direction from them should additional wildcats be drilled?

In the early days of the Association, before the various gadgets to make logs were invented, but after it had been agreed that the geological conditions could not be determined satisfactorily from drillers' logs, it was common for our members to spend many hours on the floor of the rig—an experience now verging toward obsolescence. Taking geologists off rigs is likely to continue, but I am afraid we may thereby lose something, and become: "Type of the wise who soar but never roam."

What do we want to know about a well which is drilling exploratory footage? In the old days, the most important questions were: Are there showings of oil and gas, in what kinds of formation, and of what age? Examination of samples as fresh as possible was considered important, hence the geologist on the rig. But we did not worry about the presence of structure, because the most exploratory wells were drilled after surface mapping had showed folding; on wells drilled without previous geological mapping in those days there was usually no geologist, because they were tolerated only on wells in which they could claim some responsibility for the location.

To-day, we are drilling many wells where there is no clean-cut surface structure, so in addition to the three old questions: Are there shows of oil and gas, in what kinds of formation, and of what age?, we now add a fourth: Does drilling confirm the existence of a favorable structure? And a fifth: How is the well situated on that structure?

The first question, as important to-day as formerly: Are there shows of oil and gas?, is particularly important in exploratory wells drilled remote from known oil fields. Authentic evidence of oil and gas in such an area demonstrates that hydrocarbons were formed—surely a basic reason for exploratory effort.

In addition to the shows of oil and gas in quantities which are easily discernible, traces have been measured by micro-chemical techniques, to investigate (1) Do non-commercial reservoirs in the exploratory well indicate commercial production from the same horizon nearby, and (2) Do shows toward the bottom of the well indicate oil and gas below the total depth drilled?

Since studies concerning the way these two questions can be answered are geo-chemical, they are not primarily geological, and fall outside the scope of this paper.

The second question we ask concerning the exploratory well: What are the reservoir rocks? At present, we depend largely on logging devices, supplemented by cores. These data are considered adequate to decide whether to set casing or to make drill-stem tests. Are they adequate to give us evidence of favorable reservoirs nearby, which are not favorable in the well itself?

Let us consider three types of reservoirs, and how to locate their distribution by evidence from their marginal facies, that is, from samples outside the most

favorable area. These three types are sand, reef-limestone, and fracture-zone.

Sands and sandy clays may be divided into two classes: sorted and non-sorted. So-called sandy clays or sandy shales which can be proved to be sorted are usually alternations of a thin sand bed and a thin silt bed, many times repeated, and may themselves be commercial reservoirs. The thin sand beds in such an alternation, in many cases, are coarse enough to demonstrate that strong currents transported them, and to suggest that in the vicinity more available clastic material will result in thicker sands. To evaluate such a possibility not only the coarseness, but the grading, needs to be considered. On the other hand, ill-sorted sands and true muds not silts, especially those high in carbonaceous matter and in oxidized particles, suggest local flooding from land areas, and are not as favorable as are alternations of sorted sands and silts.

Study of present sedimentation in submerged areas near large river mouths in comparison with areas away from the rivers, will help in this problem of interpretation of sandy beds in exploratory wells. Such studies of sediments are especially useful where stratigraphic traps are being sought.

The second class of reservoirs—reef limestones—would be expected to occur where calcium carbonate is abundant in the water, and therefore calcareous sediments should be found over an area greater than that occupied by the reefs themselves. In the paper by Conselman and Conley,[3] at this meeting, the vertical distribution of calcareous sediments is described in one area, as indicative of the geological stages at which reefs would be most likely to have been formed.

Even where limestones are not present at any horizon in an exploratory well, there can still be evidence for reefs. Some shales will suggest the occurrence of limestones in the vicinity. A chemical study of a group of shales when the material originally was colloidal, and not silt, showed that they can be classified in three sharply defined groups: non-calcareous, less than 5 per cent calcium carbonate; slight calcareous, 15–20 per cent calcium carbonates; and marly, over 50 per cent. The marly shales are evidence of abundant lime during deposition, and correlate with near-by limestones in many areas. We therefore should classify the shales in an exploratory well as to calcium carbonate content if we are looking for limestones in the area.

The third reservoir type—fracture zones—is important, as described in the January *Bulletin* concerning the Santa Maria district in California.[4] The causes of fractures in different districts may be different, but extensive fracturing is probably localized in "hard brittle rocks," and their distinctive lithology should be evident some distance away from the fractured area, and should be mapped in exploratory wells where the fractures themselves are absent.

The symposium on facies which our research committee held at this meeting comprised case histories which involved lithologic changes in reservoirs with which we concern ourselves when we study exploratory wells.

[3] Frank B. Conselman and J. N. Conley, "Limestone Development in the Pennsylvanian of the Eastern Permian Basin, Texas."

[4] Louis J. Regan and Aden W. Hughes, "Fractured Reservoirs of Santa Maria District, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 33, No. 1 (January, 1949), pp. 32–51.

Our next question is: Is the exploratory well on structure, and how shallow does the structure show? We have two kinds of areas where the question is to be answered: folded areas, and areas of very low regional dip.

It is not always too easy to know how a well is located on structure at depth merely from its location with relation to the surface structural axis. Figure 1 is

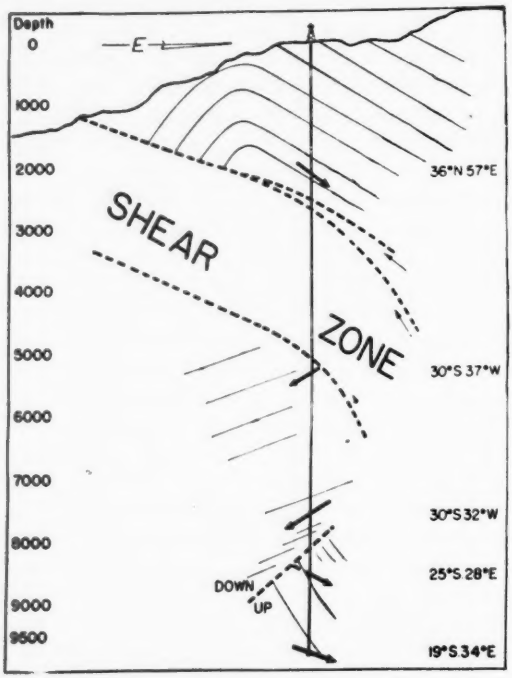

FIG. 1.—Surface anticline with complex structure below interpreted with aid of dip-meter readings.

a case where the dips in the wells were nearly the same in amount, but differed markedly in strike, so that the well was not testing the kind of a structure inferred from the surface outcrop.

In such cases, either oriented-core or dip-meter data are essential to a proper interpretation of the structural position of the well.

In areas of low regional dip, steep dips in cores are generally considered evidence of local folding. If, however, the cores show no steep dip, folding may still be present, and we seek other evidence, such as thinning of section or faulting. Thinning of section which is progressive can be interpreted as progressive uplift or increased compaction; if local, is considered associated with uplift.

The difficulty in using these criteria of thinning and local faulting to establish the existence of a structure is that most geologists are ready to deduce them only

from correlation with adjacent wells, but are hesitant to interpret evidence for these criteria from exploratory wells which are remote from other wells. Even with wells nearby, we have seen many interpretations of the existence of structure from shallow beds which did not seem to be confirmed as the well deepened. Cases will come to your mind of thickening of beds with depth so that a postulated shallow structure appears to disappear in depth, instead of increasing in relief, without change in dip to explain the reason. Sections on two sides of a fault fail to correlate in thickness.

I feel we need more study of closely drilled structures as to thickness changes to strengthen our interpretation of partially drilled areas. Particularly I call attention to the quantitative study of compaction in this connection.

When the exploratory well is remote from others, and we want to locate thinning and faulting while the well is drilling, as a help to answer the question: Is structure present in the exploratory wells?, we must recognize that new techniques are in demand. How shall we decide what ones to try out? Let us change the question to an equivalent one in a tectonic form, as a clue, so that our question: Is structure present? then becomes: Is there lithologic evidence of the application of stresses to the rocks other than the weight of the overburden?

In this form, the question suggests various techniques, and we join geologists in fields other than petroleum for the attack. I shall cite two descriptions of the work in other realms.

In coal fields, it is important to find out about stresses other than overburden, because stresses at an angle to the bedding planes may have caused reduction in strength of roof and floor of the coal mines.

Attention to this problem has been devoted for many years in England, and to show evidence which has been collected, I quote from a report in 1896.

> In beds of the Coal Measures in undisturbed bands suitable sections of clays and shales show that the micaceous mineral is very nearly all flat in one plane; but in some of the more indurated, and what might be called more advanced, samples examined, this is not so completely the case. The great bulk of it is still flat in one plane in which it gives, in polarized light, a dim speckled field; but this field is crossed by little veins and strips and wider bands, highly inclined or even vertical to this plane, or a minutely felted and wavy mass of flakes of the same or similar mineral, but obviously in a more developed stage. There is no mistaking that these veins and bands have been formed later than the main mass seen in the section.[5]

A very recent similar attack is described as follows.

> Field work in the Laramie Range, Wyoming, has led to the concept of migration of chemical elements along planar features such as layering, schistosity, and sub-parallel, closely spaced fractures, in the host rock. . . . It is in accordance with the strain-stress theory to suppose that during each spasm of stress, planes of certain attitude would have least normal pressure and thus form "openings," whereas, others, differently oriented, would have most normal pressure, and thus be the most "closed" planes of the region.[6]

[5] Hutchings, *Geol. Mag.* (1896), p. 312. See also comments by D. W. Phillips, *Geologie en Mijnbouw* (October, 1948), p. 230.

[6] W. H. Newhouse, A. F. Hagner, and G. W. DeVore, *Science*, Vol. 109 (February 18, 1949), p. 168.

At least one petroleum geologist attacked this problem in the search for buried ridges. He reasoned that soft clays which were the surface formation, should be mobile over the ridge, and therefore should have tended to move from the top towards the flanks, resulting in cracking on top. He therefore took samples cut in the form of cubes from pits below the surface soil, and exposed them to drying for a uniform time. Joint cracks were thereby made manifest, and he recorded the number of cracks per cube on a map of the sample localities. Connection of the points of the same crack number gave a maximum number of cracks over the ridge, and a decrease off it.

A second empirical method was used in the early days of reflection shooting at moderately deep salt domes. It was at that time difficult to correlate events on the seismograms. A map was made of the shot points, with the number of reflection events figured at each shot point. The map showed a minimum number on top, a maximum zone around it corresponding to the flank of the salt dome, and another series of small values beyond the dome area.

I have made a study of the core descriptions of two wells drilled on the flanks of a shallow piercement dome, and found that jointing, veining, or small faulting was reported from 30 per cent of the cores. Two wells in the same county drilled away from this salt dome were compared, and I found that there was not a single core which was described as jointed or faulted.

Such data can be studied where there are many cores from an exploratory well, but in many exploratory wells to-day coring is performed very sparingly, and unless the geologist can show, by examples such as the ones just mentioned, that coring is important to the proper and complete interpretation of the well, he may be seriously handicapped.

At the present time, drilling costs are quite high. In addition to the high footage rate, there is a high rate for special jobs, such as coring. The oil operator can not see a chance to reduce the footage cost, but by reducing coring, he can reduce the total cost of the well. Therefore, at the present time, the geologist must have very persuasive reasons for his coring recommendations, and he must show valuable data are being obtained from the cores, otherwise he may not be furnished as many as he needs.

Lithifications above structures involving changes in electric resistance, secondary chemical compounds, and higher velocity of sound waves have been mapped by various investigators, including Rosaire, McDermott, and others.

All of these suggested exploratory methods to verify the existence of structures in exploratory wells are based upon the theory that the stresses causing the structure have modified the physical characters of the rocks, and also the fluids in them. If the evidence can be seen on the beds near the surface, it should also be apparent in those being drilled at depth in the exploratory well, and the effects will depend on the orientation of the stress relative to the bedding of the rocks, and its relative intensity to the stress on any element due to the overburden at that time. Local faults are the large-scale effects of such stresses, but there are smaller effects which we should be able to demonstrate easier than we can prove faulting.

Most of us think of lineation, as defined by Cloos, and described in the recent Geological Society of America *Memoir*, as a phenomenon discernible only in strongly metamorphosed sediments. I suggest that evidence of slip should be sought in less strongly folded and metamorphosed rocks. To help find such evidence in exploratory wells, we should record similar data on the surface outcrops over known structures.[7]

The problem of locating a fault in an exploratory well is a special case of the general problem just described of locating evidence of stress. Faults are usually mapped to-day, purely on correlation of wells, not on direct evidence of the fault itself, but where there is only one well, correlation is unavailable, so we must try to find direct evidence of the fault.

Our logging techniques are already numerous, and others are in development. What are our prospects of picking a fault point in a well from them?

Some years ago, the Germans were fond of a theory that fault planes showed greater radioactivity than the rocks adjoining them. The limited data available from gamma logs to date, and from measurements directly on surface faults, are negative in the Gulf Coast.

A caliper log might be presumed to show faults in two ways: reduced hole size at a fault which crosses soft, young, rocks; enlarged hole size at a fault accompanied by shattering which crosses old, hard, rocks. There is a little positive evidence in both directions, but further investigation is necessary.

To decide about the utility of other logging devices, we must know more about faults. Published maps show no drag on young beds in the Gulf Coast; maps in areas of hard rocks show drag in some cases, in others, no drag.

I fear this is largely a conventional treatment of the fault, and we should review our geological inferences by references to all the data in every case, and we may need more data in the form of cores from both sides of faults, but near them to decide on the presence of drag. Possibly more dip-meter surveys at and near faults will be equivalent to more cores. Figure 2 illustrates a case from Heidelberg, Mississippi, where it just happened that dip-meter readings were made near the major fault of the field. It will be observed that significant evidence of the drag near the fault is furnished by the dips.

Even where there is no drag at the fault, and no shattering, there should be some disturbance of the geometry of any clastic formations. Such movement of sand grains results from stresses prior to the faulting, and can be evident from a change in porosity or permeability, or from disturbance of bedding planes. Figure 3 is a case from the outcrop of a small fault on the flank of a salt dome, which demonstrates such disturbance, which has controlled the circulation of mineralized water.

In looking for minor displacements and changes in permeability as evidence of faulting, or of structure in general, it must be remembered that there are changes which result from diagenesis and compaction which result in similar

[7] A similar recommendation for the study of faults and joint systems in oil, gas, and salt domes, was made by Robert Balk in his paper entitled "Structure Elements of Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 1 (January, 1936), pp. 51–67.

joints which are not evidence of any other stresses than that due to the overburden.

Geologists should remember that the pressure due to the overburden is distinct from hydrostatic pressure, and in this connection, there will be given at this meeting a paper: "Pore Space Reduction in Sandstones," by Miss Jane M.

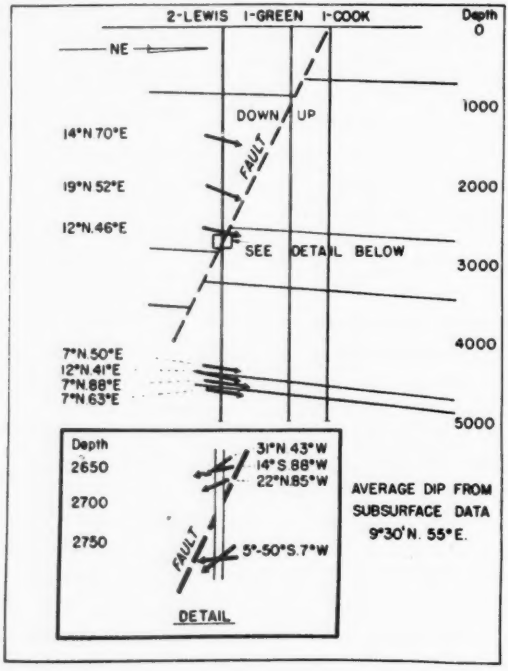

FIG. 2.—Evidence of faulting from dip-meter readings in well crossing fault. Heidelberg field, Mississippi.

Taylor, which discusses pore-space reduction phenomena related to depth below the surface.

In addition to evidence for a fault crossing an exploratory well, we are interested in evidence of faults near the well, but not crossing it, and in evidence as to the age of folding and faulting. There has been some study of the angle between direction of stress and direction of slip, and it has been proposed by Hartmann that the larger this angle, the more lithified the rocks. This is only an hypothesis, but deserves study by petroleum geologists, because its verification would give us another tool to decide age of folding and faulting.

In this field of interpretation of exploratory wells, we can use scale models, but we can also profit from more field work on outcrops in faulted areas and in mines of the kind recently carried on in the coal mines of Holland. Every mine in

the sedimentary rocks near oil fields should be studied by the geologist.

The geological interpretation of exploratory wells to-day involves the study of samples and cores by our present techniques. For similar material on which to test new techniques and methods of interpretation, we shall have future exploratory wells, but there will be a gain in time if we can apply these techniques to material already on hand. This implies that we are preserving adequately the samples and cores we are collecting currently. This is only true to a limited extent, and to cope with this enormous task of preservation and storage, your executive committee has set up a special committee to make recommendations not only for material from exploratory wells for oil and gas, but from all wells in sedimentary basins.

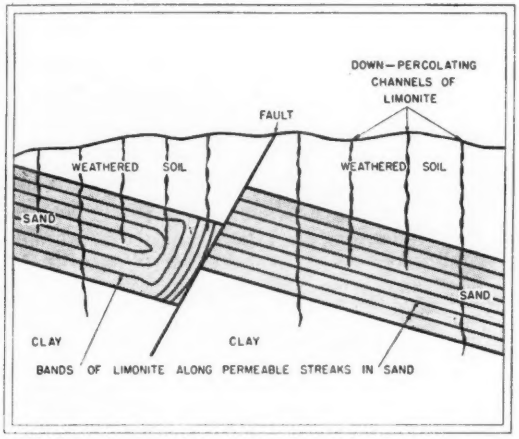

FIG. 3.—Evidence of faulting from distortion of beds on downthrown side. Outcrop, east flank, Ixhuatlan field, Mexico.

Many of the basic data for new techniques can be obtained from outcrops. The affiliated societies have established a great prestige for their field trips, because they have been effective in investigating stratigraphic problems from outcrops. I hope they will also plan their field trips to include studies of lineation and other evidence of folding and faulting.

I have indicated that there is work necessary in the field, in the collection of more kinds of logging records, and in the lithologic study of cores and cuttings, before we can get more definite answers to those questions which arise in the geological interpretation of exploratory wells. Let us remember that these questions are:

First: Are there shows of oil and gas?
Second: What are the reservoir rocks?
Third: Is there favorable structure?
Fourth: How is the well located relative to structure?

Those of you who have long experience in watching the drilling of exploratory wells will realize we need new help in answering these questions while the well is drilling. For younger members, I will cite a typical case which shows the seriousness of this problem of interpretation of exploratory wells.

In the description of the Creole field, published in Volume III of *Structure of Typical American Oil Fields*, edited by J. V. Howell, one exploration is described as follows by Theron Wasson.

> The production of the Creole field . . . is controlled by minor faulting which has been discovered as wells were drilled. Since no other test had been drilled near Creole it was impossible to detect faults in the discovery well which was drilled vertical to the total depth of 9,394 feet. The discovery of oil in this first test . . . was accidental, as the test happened to cut the up side of the State sand close to a fault which was properly sealed by shale beds. If this test had been located 300 feet farther northwest, it would have been a dry hole and the Creole field would not be known.[8]

You see that Mr. Wasson did not see the faults in this first well, because the technique then in use required other wells nearby, so that faulting could be deduced from correlation, and those other wells were unavailable at that time.

I hope the case histories will soon be written without words such as "accidental" and "happened to cut the upthrown side." The new lines of attack on problems like that of the first well at Creole will probably not result in new techniques which are always definitive, but I urge that they be attempted, and at once and intensively.

This job should be as challenging to the younger geologists who will find our future fields which are *without* surface structure, as was to the geologists of a generation ago the finding of fields *with* surface structure. The younger geologists have geophysicists as aides in locating the well, but they should use all the geology in the interpretation of the exploratory well while drilling.

I am sure that the basic training of our younger geologists is adequate preparation for the attack along more explicit lines of the geological interpretation of drilling wells, and I ask you to "go to it," wishing you success in this baccalaureate greeting:

Joy to the laughing throng
That from the threshold starts,
  Led on by courage and immortal hope
  And with the morning in your hearts.
You to the disappointed world shall give
The life we meant to live
Beautiful, free and strong.
  The light we almost had
  Shall make you glad.
The words we waited long
Shall run in music from your voice and song.

[8] Theron Wasson, "Creole Field, Gulf of Mexico, Coast of Louisiana," *Structure of Typical American Oil Fields*, Volume III, Amer. Assoc. Petrol. Geol. (1948), p. 289.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1145-1153

TRENDS IN SEDIMENTOLOGY[1]

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Since the organization meeting of our Society 22 years ago this month, we have grown from a handful of specialists to a group of considerable size with greatly broadened interests. Our membership to-day totals 535, an increase of 27 per cent during the past year. Our two journals are now recognized as so outstanding in their special fields that we have more non-member subscribers than members; the *Journal of Paleontology* has a mailing list of 1,238, and the *Journal of Sedimentary Petrology*, 702. Our founders were chiefly concerned with problems of subsurface correlation; they consisted primarily of "foram" men with a sprinkling of "mineral grain" experts. To-day, subsurface correlation is only one aspect of the broad problems we are called upon to solve. In the application of our branches of geology to the search for oil and gas we have come to realize that almost every phase of paleontology has potential value, and that a thorough knowledge of the origin of sedimentary rocks is essential to their proper interpretation. The four symposia at this joint annual meeting, two sponsored by our Society ("Quaternary of the Gulf of Mexico" and "Fundamental Problems in Paleontology") and two by our parent organization ("Control of Oil and Gas Accumulation by Sedimentary Facies" and "Reefs"), evidence this broadened interest and the increasing importance of paleontology and sedimentology in petroleum exploration.

We have also achieved a closer coordination of the two special branches of geology represented in our Society—Paleontology and Sedimentology.[3] Judged by membership subscriptions to our two journals, about 55 per cent of our members class themselves as paleontologists and about 45 per cent as sedimentary petrologists, but this division is more apparent than real. In the application of paleontology and sedimentology to oil finding—in fact, in any broad program of research into the origin and history of sedimentary rocks—it is impossible to separate these two branches of geology. The physical, chemical, and biological aspects of sedimentary rocks are largely dependent upon each other, and all are affected by, and reflect, the environmental conditions under which the sediments were formed. The importance of this relationship has been abundantly demonstrated in recent years, particularly in the Gulf Coast, where neither the methods

[1] Presidential address, presented at the 23d annual meeting of the Society of Economic Paleontologists and Mineralogists, St. Louis, Missouri, March 15, 1949. Manuscript received, April 27, 1949.

[2] United States Navy Electronics Laboratory.

[3] The word *mineralogists* in the title of our Society unfortunately reflects the narrow range of interest in sediments common among petroleum geologists 25 years ago. The term *sedimentary petrology*, used in the title of our journal devoted to this field, is more expressive of our present interest in all aspects of the study of sediments and is preferable to the more restricted terms *sedimentary petrography* and *sedimentation*. *Sedimentology*, synonymous with sedimentary petrology, has the further advantage of brevity without sacrifice of clarity.

of paleontology nor lithology are adequate by themselves for interpretation of the sediments, or even for the correlation of sedimentary horizons, and only a combination of all lines of attack suffice to unravel the complexities of Gulf Coast stratigraphy. The association of these two branches of geology in our Society is thus not only a natural one, but a potential source of strength. I would therefore like to review the progress of our Society in both of its branches, but lack of both time and knowledge limit me to some general comments on the development of sedimentology.

The first issue of the *Journal of Sedimentary Petrology*, published in May of 1931, contained an editorial by Henry C. Milner entitled "Sedimentary Petrology in Retrospect and Prospect." Concerning the state of the science at that time, Dr. Milner wrote:

> Slightly more than twenty years ago studies in sedimentation and sediments as a whole were, with a few outstanding exceptions, conspicuously neglected, judged by present-day standards of technique and research. The lessons of Sorby and his successors were certainly not assimilated by geologists as a body, whose apathy to this branch of petrology in the period between his work and the end of the first decade of this century, was as well known as it was surprising. Such indifference dies hard even today with some of the more conservative members of the profession.
>
> Then the vista suffered by vision through the wrong end of the telescope. The stratigrapher was content with a few general labels to describe his lithology. Sandstone was just sandstone and little more; when its color, texture and other superficial characters had been noted, it had been given its due, and nothing further commended it for study for its own sake, apart from that readily accorded to any indigenous fauna prevailing. The significance of such latent indices as accessory minerals, and especially of those quantitative elements which a thorough investigation of sediments could provide, was scarcely if at all appreciated. And by contrast, rocks only incidental to the geologic column were studied with a degree of intensity which has never flagged and which has always been the outstanding feature of igneous petrology. The application of microscopy, which made possible the science of igneous petrography, failed to awaken interest in deposits nearly always taken for granted until the "heavy" mineral asserted itself and proclaimed a new line of investigation.
>
> However much we may seek to deplore and erase any impression of synonymity of "heavy" mineral work and sedimentary petrology, the fact remains that the pioneers in this field loosed the vitalizing force which was destined to revolutionize events. At first the "heavy" mineral was regarded as an inconsequent accident, a fascinating departure from that knowledge which could be gleaned from thin-sections. Its precise bearings on the history of the deposit from which it was segregated remained for long unappreciated until at the end of the nineteenth century certain European investigators expounded its possibilities. Previously it had escaped attention, lost in the wilderness of undeciphered rock-matrix; the aggregate rather than the particle was scrutinized. *Its advent substantially reversed the order of things. The particle became the goal of inquiry.*[4] Not only its composition but its size and shape were studied, thus individuality established. Detrital matter of all kinds was soon subjected to most minute analysis and the same principles were applied forthwith to consolidated rocks which, in a crushed state, became amenable to this treatment. Not only rocks of mechanical origin, but all types of sedimentary deposit were thus searched for the new evidence, with the result that this branch of petrology developed into a firm culture with a following destined in a short time to become international. . . . The quantitative element, hitherto lacking in this petrology, became an acknowledged desideratum; precision in measurement and expression compelled all the aid which crystallography and physics could afford. Sedimentary petrology thus came to embrace every relevant method of analysis capable of facilitating its study and gained enormously from the fact that its new terms of reference were widened by the appeal to so many sister sciences.

Dr. Milner thus painted a glowing picture of the progress of sedimentary petrology from 1910 to 1930. I have tried, and failed, to formulate a statement of the status of the science to-day that will show an equivalent development since 1930. As a matter of fact, Dr. Milner's general statement is essentially as applicable to-day as it was when he wrote it. Probably we should not expect so spectacu-

[4] Italics by the present writer.

lar an advance; the first stage of development of any new branch of science is characteristically more rapid than in any equivalent subsequent period. A period of rapid growth must be followed by one of critical review and consolidation, if the next advance is to be built upon a solid foundation. How much, then, have we accomplished in the past 20 years?

From the standpoint of mere bulk of published papers, our accomplishments bulk large indeed compared with those of the previous period. Our knowledge of the characteristics of sediments has increased tremendously; many sedimentary formations have been described in a detailed and quantitative fashion unknown 40 years ago. Following the Huttonian principle that the present is the key to the past, a great deal of attention has been devoted to Recent sediments and to sedimentary processes. But the mere accumulation of data does not necessarily make for progress. Of course description must precede interpretation, but in 1931 Milner, acknowledging the criticism of undue emphasis on purely descriptive work, thought that we had reached the point where explanation was commencing. Is it still "commencing"?

Advances in interpretation are difficult to assess, but frequently they follow the development of new methods of attack or new techniques. Let us see, then, what major new techniques have been developed during the past 20 years. Consider first the methods of studying and measuring the bulk properties of sediments, such as color, luster, cementation, porosity, permeability, and bulk composition. Though some quantification and refinements have been made in some of the methods of measuring these characteristics, have any radically new departures been developed by sedimentologists? Petroleum geologists and engineers, under pressure to develop more rapid and accurate methods of subsurface correlation, have produced powerful tools in the form of electrical conductivity and resistivity logs and radioactivity measurements. Meanwhile the specialist in sediments has continued the trend of 20 or 30 years ago, concentrating his attention on methods of studying and measuring the fundamental properties of individual particles; their composition or mineralogy, their size, shape, roundness, and surface textures. Have any spectacular advances been made in these methods or techniques?

With respect to mineralogical determinations, the petrographic microscope is still the chief tool of the sedimentary petrologist, as it was 20 years and more ago. Spectroscopy and X-ray analysis have proved to be extremely valuable in the study of clay minerals, but so far they have found little application to the study of other constituents of sedimentary rocks. Perhaps we are overlooking valuable possibilities in this field; unique varietal characteristics of detrital minerals might be determined by the identification of trace elements, using the spectrograph or isotope analysis. For correlation, and for provenance studies, spectroscopy and radioactivity determinations may prove to be more powerful and rapid tools than the petrographic microscope.

Methods of determining the sizes of sedimentary particles, and particularly

their size distribution in mechanical sediments, have been greatly refined and made much more accurate during the past 20 years. But are size analyses made by the most modern methods much more useful in reaching our ultimate goal of determining the origin and history of a sediment than were the rough methods of 20 years ago? I doubt it, for the refinements have been chiefly in the analysis of the finer constituents—particles of silt and clay size—where the value of a size analysis by any method is dubious. Analysis of these fine constituents requires disaggregation and dispersion of the individual particles. Since these particles are not disaggregated in the original sediment, the size distribution measured is not the one that actually exists in the sediment itself. Furthermore, since various diagenetic processes have acted on the particles since their initial deposition, the size distribution in the sediment, even if it could be measured, is not that which existed when the particles were deposited. Recent studies indicate that even sediment samples removed from a stream or lake and analyzed for size distribution in their native water will not give reproducible results; the analysis varies with the sediment concentration and with the length of time the sample is allowed to stand before analysis. Duplicate analyses of the same sample may vary by a factor of three in median grain size and in percentage of clay-sized particles.[5] From the standpoint of the interpretation of sediments only a few months old, to say nothing of those millions of years old, it therefore appears that we may have been over-refining our methods of analysis. Rather than devoting further effort to additional refinements, it seems to me that we should critically evaluate the usefulness of size analyses and, in the light of this evaluation, agree upon a simple standard method which will yield reproducible results, which is sufficiently accurate for our purpose, and which is, above all, rapid and cheap.

With respect to the shape and roundness of sedimentary particles we have, in the past twenty years, realized the fundamental distinction between these two properties, and developed several methods of measuring them with varying degrees of accuracy. Even the most rapid and approximate of these methods, however, are rather time consuming, particularly when applied to the sand sizes, and their value in interpretation has not been completely demonstrated. These techniques would therefore seem to have limited usefulness, chiefly in the study of the coarser detritals.

Still less advance has been made in the study of the surface textures of sedimentary particles. We have not yet developed any quantitative method of expressing textural characteristics, and many of the earlier conclusions regarding the significance of such features have not held up under close scrutiny. "Frosted" surfaces on quartz grains, for example, once thought to be a safe indication of eolian action, apparently may develop subsequent to deposition by solution and re-precipitation of quartz. Perhaps there are several types of "frosting," some of

[5] For example, see C. S. Howard, "Laboratory Experiences with the Bottom Withdrawal Tube Method of Size Analysis," *Proc. Federal Inter-Agency Sedimentation Conference* (January, 1948). pp. 235–45. Bureau Reclamation, United States Department of the Interior, Washington, D. C.

which accurately reflect the effects of a particular agent or environment, but much more careful and accurate studies must be made before this can be demonstrated.

Closely related to the properties of the individual sedimentary particles are their properties in the aggregate; their size distribution (already mentioned), mineral distribution, distribution by shape and roundness, their orientation, and the resulting features of rock texture and structure. The complex interrelationships of these various characteristics, and the degree of their dependence on the agent of transportation and environment of deposition, were scarcely realized 20 years ago. Here we have learned much as a result of the application of quantitative methods and of basic physical and mathematical principles, chiefly through the work of Krumbein and his students. Consider, for example, what is now known about the interrelationships of size, shape, and mineral composition. Twenty years ago it was well known that the micas were most abundant in the coarsest sizes of a sandy sediment and that the "heavy" minerals were concentrated in the finer sizes. But the implications of this distribution were scarcely realized; it was assumed that a series of sand samples from the same source and deposited by the same agent would have essentially the same mineral composition and distribution of minerals by sizes. We now know that this is not the case. As Rittenhouse and others have demonstrated in studies of Recent sands, the mineral composition of a sediment is not only dependent on the size distribution, shapes, and relative abundance of minerals in the source rocks, but also on the absolute and relative amounts of mechanical and chemical disintegration of the source rocks (and of the minerals during transportation), the absolute and relative rates of transportation of the different minerals and of different sizes of the same mineral, and finally, on the hydraulic conditions existing at the time and place of deposition. The other characteristics of the sediment are also in part interrelated, and also determined by a similar set of complex variables, some of which are dependent and some independent. When it is remembered that many of these characteristics become obscured by diagenetic and other changes taking place after deposition, the difficulties encountered in attempting to unravel the history of a sedimentary rock become self-evident. Forty years ago, when almost all of our knowledge was qualitative, sediments appeared to be relatively simple. Interpretations were based on a few sweeping generalizations. Twenty years ago, with new methods of attack and with quantitative techniques being developed, we realized that the interpretation of sedimentary rocks was a more complex problem than we had thought, but the new methods gave us high hope for a rapid solution to the problem. To-day, with no radically new techniques, but with a great deal more quantitative information accumulated, the complexity of the problem is much more obvious.

At first glance this prospect looks most discouraging, but so far we have been looking only at the dark side of the picture. Though interpretations of sediments were considered comparatively simple forty years ago, such interpretations were

very general and of relatively little value; they were also frequently wrong. We have now demolished most of the old generalizations and theories. If we have not yet developed a set to replace them, we have at least learned that interpretative theories must be based on a sound foundation of observed fact and of physical and chemical laws. Though we have developed no radically new techniques, we have greatly expanded two methods of attack which were in their infancy 20 years ago. First, we have learned to make much greater use of quantitative methods and of mathematical and statistical tools. The accumulation of quantitative data has revealed information unsuspected from qualitative descriptions, and has made the data of each worker usable by every other one. Also, the relative validity of conclusions can, in many cases, be tested by standard statistical means. Second, we have made a great many detailed studies of Recent sediments, where the effect of process upon product may be observed without the complicating and obscuring factor of later changes.

These two lines of attack still appear valid and most likely to yield additional useful results. That this point of view is generally accepted is evidenced by the detailed analysis of research in sedimentology recently made by the A.A.P.G. research committee. Both the necessity for quantitative data and for greatly increased effort in the study of Recent sediments and processes is evident throughout the report of that committee. If the American Petroleum Institute supports this project, we can look forward to a considerably expanded program of study during the next few years.

Before embarking on such a program, however, it would seem well to critically re-examine our methods of attack. Since we have no radically new techniques, we must make the most of presently available ones, and not waste effort on those which promise minor results for major expenditures of effort. In particular, it seems to me, we must remember that no matter how much we draw upon the sister sciences of physics, chemistry, and mathematics (including statistics), we are primarily geologists, whose ultimate goal is to unravel the history of the rocks. No amount of quantitative data on the characteristics of an individual sample or series of samples will solve our problems unless set in the proper frame of reference. To me, this means that laboratory work must go hand in hand with field work. I have the feeling that, during the past 20 years, our enthusiasm for developing quantitative methods and improved techniques may have led us to spend too much time in the laboratory and too little in the field. Many of the gross features of ancient sediments can not be transported to the laboratory, they can only be appreciated by detailed field mapping and observation. Many of them can not be observed in Recent sediments; an excellent reason for the concomitant study of Recent and ancient sediments, and a compelling reason why every sedimentologist should have thorough training and broad experience in field geology.

In the study of Recent sediments, field work also involves the study of processes of sedimentation, as well as the sedimentary product. This means that hydrology and oceanography must go hand in hand with sedimentology. It is not

sufficient to collect a series of samples and take them back to a laboratory for analysis; the conditions under which the samples were deposited must be carefully observed, and the collector must be sufficiently familiar with both process and product to recognize the effects of successive or changing processes, and adjust his sampling technique accordingly. Scattered and unplanned observations are also of little value; any research program which is to achieve worthwhile results must be carefully planned from the initial observations in the field through laboratory analyses to the final correlation of results. Since funds and personnel are not unlimited, effort must be concentrated on those aspects of an investigation most likely to produce results. We have already reached the point where we can easily collect more material then we can analyze by present methods with available personnel. A single oceanographic expedition of 2 or 3 weeks duration, for example, can collect enough cores and samples of marine sediments, not to mention the concomitant oceanographic data, to keep 3 or 4 people busy in the laboratory for 2 years or more. During 1949 it is probable that more than 500 cores of the ocean bottom and several thousand surficial samples will be collected by the Woods Hole Oceanographic Institution, the Scripps Institution of Oceanography, and Navy establishments such as the Hydrographic Office and the Navy Electronics Laboratory. The amount of work involved in analyzing all of this material for size distribution, mineral composition, organic content, organisms, and other characteristics is appalling.

It therefore seems to me that every program of research must be carefully planned to include the following: (1) a general survey of the problem, preferably in the field, with the objectives of the program always in mind; (2) a carefully planned program of combined field observations and sampling, with the methods of sampling and the distribution of samples planned in accordance with field conditions and the objectives of the study; (3) proper collection and preservation of the samples to retain the characteristics which it is desired to measure unchanged (preferably, the samples should be so preserved that subsequent work on other properties can be done by later investigators); (4) a careful choice of laboratory techniques to produce the maximum amount of applicable information with the minimum expenditure of time and effort, using mass production methods wherever possible; (5) coordination of field and laboratory results by someone familiar with both aspects of the problem.

This ideal arrangement is not always possible. The study of ancient sediments, particularly those beneath the surface, often depends on well samples that have not been collected with the specific purposes of the research project in mind. The same is true of Recent samples, particularly marine sediments collected in connection with other studies. Such samples may yield valuable information, particularly if they have been properly taken and properly preserved. The A.A.P.G. executive committee is well aware of these problems in connection with well samples, and has set up a committee to investigate proper methods of obtaining, preserving, and storing the valuable cores and cuttings taken from wells all over

the country, many of which have been wasted in the past. Similar problems exist with respect to samples of Recent sediments; many cores taken in connection with engineering studies of one type or another are destroyed, simply because of the difficulty of storage. Methods of obtaining samples and cores vary widely and are badly in need of standardization, as are methods of preserving and storing. The American Geophysical Union is aware of this problem in connection with the increasing number of cores of deep-sea sediments.

In summary, the trend away from qualitative field studies of sediments toward quantitative laboratory study, begun 40–50 years ago, has continued and has become much more pronounced, especially during the past 15 years. Although this trend has been most fruitful and certainly should be continued, it seems to me there is danger that, in our enthusiasm for quantitative laboratory techniques, we may neglect the advantages of field work. Already methods of investigation have become too time-consuming and too divorced from the broader features of sediments evident only in the field. Standardization and simplification of analysis methods are needed, together with a closer integration of field and laboratory study. The trend toward greater emphasis on Recent sediments, begun 15–20 years ago, is continuing and should continue, and should be even more closely integrated with studies of sedimentary processes if we are to develop the new principles and laws essential to the interpretation of ancient sediments. The trend in the past few years toward integrated studies of both the physical and biological aspects of sediments is particularly promising and should be encouraged.

Finally, I think that we as a Society should consider what we can and should do to aid in the development of our branch of science. We are the only society whose primary concern is the study of sediments; according to our constitution the object of the Society is "to promote the science of stratigraphy through research in paleontology and sedimentary petrology, especially as these relate to development of knowledge of the geology of petroleum." It does not seem to me that we, collectively, have been doing all we might to fulfill this object. For example, instead of formulating an integrated program of research in sedimentology leading to a greater use of the science in the discovery of additional oil reserves, we have waited for the research committee of our parent organization to do it for us. Rather than sponsoring standardized terminology, analysis techniques, and summaries of existing information, we have waited for the American Geophysical Union, the National Research Council, and the federal agencies involved in sedimentation studies to do it for us. It seems to me high time that we, as a Society, participate more actively in the development of stratigraphy and sedimentology. Perhaps we have been too involved in our own specialties; we have been measuring the thickness of the bark of individual trees and making statistical summaries of its variations while others have been surveying the forest. If we are to remain an alive and growing organization, it seems to me that we must assume a greater share of the responsibility for developing the science.

Specifically I would recommend the following.

1. That the Society of Economic Paleontologists and Mineralogists, either through its research committee or by other means, participate more actively in planning research projects in the fields of stratigraphy and sedimentology, particularly as related to petroleum exploration.

2. That the Society, either individually or in cooperation with other agencies such as the American Geological Institute, the National Research Council, and the American Geophysical Union, establish groups or committees to:

(a) Study existing methods for the analysis of sediments with a view to establishing simplified and standardized techniques. In the case of analyses capable of being routinized and placed on a mass production basis, such as size analyses, a central agency to make such analyses at cost might be possible;

(b) Study methods of collecting, preserving and storing samples and cores, with a view to standardizing techniques as far as possible and perhaps providing a central repository. Since our parent organization has a committee working on this problem for well cores and samples, we might well undertake a similar task for Recent sediments;

(c) Establish a central records agency, where information on research currently under way in universities, government agencies, and private laboratories would be available;

(d) Assist in periodically compiling existing knowledge and in standardizing terminology and nomenclature.

This is a big program and I am not suggesting that we attempt it alone. I do feel that we should undertake some of these projects ourselves, and should sponsor and vigorously support all of them. During the past 20 years we have grown greatly in size; let us also grow mature, and undertake the responsibilities that come with maturity.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1154-1160

GEOPHYSICS, GEOLOGY, AND OIL FINDING[1]

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ABSTRACT

As geophysics has matured in recent years, its important place as a tool in oil exploration has been generally recognized. The operation of the partnership between geologist and geophysicist is relatively straightforward in reflection-seismograph exploration as the geophysical maps are similar to those with which geologists are familiar. In geophysical methods based on potential fields (gravity and magnetic) the relations to geology are not so direct and the possible ambiguities are much greater. Close cooperation of geophysicist and geologist in the evaluation of such surveys should produce particularly fruitful results. Some specific examples of both regional and local nature are discussed.

The mutual interests of geologists and geophysicists in the broad operations of oil exploration have been generally recognized. The boundary between the proper province of the two sciences is nebulous and varies with circumstances and particular problems. If we may take the presidential addresses from this platform as a measure, the interest in the partnership between geologists and geophysicists has been much more actively expressed by the S.E.G. than by the A.A.P.G.

In the past ten years, none of the A.A.P.G. presidents has had this subject as a principal interest, but it was considered by those of the S.E.G. in 1940, 1944, 1946, and 1948. The remarks of this paper are a continuation of the theme of geological-geophysical cooperation and include some specific cases where joint consideration of the problems is necessary for a solution.

In reflection-seismograph exploration, in favorable areas, the resulting maps obtained directly from strictly physical measurements can be turned over to a geologist as an accurate representation of one or more subsurface horizons. In this case the boundary between geophysics and geology is distinct and the geologist can take the facts presented by the geophysicist and fit them into his own data and concepts of an area. To those geologists who would use geophysics as a handy tool for their work, this is an ideal situation.

In less favorable areas, as seismograph results become more complicated or less definite, an increasing amount of geological training on the part of the geophysicist, or consultation with geologists becomes necessary before a geophysical map is ready to be made a part of the usable subsurface data of an area.

There is a fundamental difference when we consider geophysical exploration based on potential fields, which for oil exploration include gravity and magnetic methods. The strictly physical part of the observations and the resulting maps, even in ideal circumstances and when carried out to any degree of precision and adequacy desired, can not give a geological picture directly. This results

[1] Address of retiring president, Society of Exploration Geophysicists, joint meeting A.A.P.G., S.E.P.M., and S.E.G., St. Louis, Missouri, March 15, 1949. Manuscript received, May 12, 1949.
The complete article, including the maps and other illustrations, as given in St. Louis, is being published in *Geophysics*, Vol. 14, No. 3 (July, 1949).

[2] Gravity Meter Exploration Company.

from the fundamental fact that there is no single distribution of mass or of magnetic material which will produce a given gravity or magnetic pattern no matter how completely that pattern may be determined.

From physical measurements the geophysicist can calculate certain limits on the anomalies of mass or of magnetization which can produce the observed picture. He can say that the anomaly can not come from greater than a certain depth; it could come from various levels or combinations of levels between the surface and that depth. He can say further, that if depths are fixed there are certain limits on the required magnitudes of the masses or magnetic bodies involved. With further information or assumption of density or magnetic contrasts, he can limit the size of the geologic deformation. Thus, if the physical data are to be translated into results useful for exploration, the geophysicist must either become geologist himself or confer with his geological partners to reduce the range of possible sources of the density or magnetic contrast to a useful exploration picture. If, as is too often the case, he has very little factual information, his interpretation, if he does more than draw an anomaly outline on a map, is based only on very general geological information and geological "reasonableness." At this stage he can hardly become a pioneer in exploration unless the limits imposed by physical analysis are such as to be outside the commonly accepted geological concepts of the area.

The most needed single item of control in connection with the geological interpretation of gravity surveys is information on densities. Density contrasts are the fundamental cause of all gravity anomalies and without them no structure would produce a gravity disturbance. The properties of a gravity anomaly, its magnitude, form and extent, are a reflection of horizontal changes in density. Such changes may be produced by structural deformation of a sequence of beds between which there are differences in density, but they also may be produced by lateral changes in the lithology of a horizontal stratum.

There have been some attempts within individual oil companies to build up a body of information which would give data on the normal density sequence in an area. This is essentially a geological problem, but we do not have more than a bare beginning of reliable quantitative information of this kind. If field geologists could be induced to become density conscious and encouraged to include the density as an item of data about each surface or core sample examined, a substantial body of information could be built up which might, in time, have value to the geologist himself quite aside from its primary interest for geophysical exploration.

In some cases it may be possible to extend density information by establishing empirical relations between vertical velocities as found in well shooting and densities, but this must be done with care and could be misleading. Gravity surveys carried out in adequate detail over well known structures may give very useful general information but will give clear-cut and definite answers only in very favorable cases.

The obvious direct answer, from a physical standpoint, is to devise a gravity-measuring instrument which could be lowered into a well to make a vertical-density log. This is technically difficult and, so far as the writer knows, has never been accomplished. Its value for gravity interpretation would certainly be considerable. With the new small and temperature compensated instruments the technical difficulties may be somewhat reduced and perhaps we can look forward to future developments of this kind.

Each of the above paragraphs on densities and density contrasts may be similarly applied to magnetization and magnetization contrasts and their relation to the interpretation of magnetic surveys.

REGIONAL GRAVITY AND REGIONAL GEOLOGY

The preceding comments are general and the problems of interpretation of potential fields are applicable to all anomalies, large or small. We usually think of such problems in connection with individual local, possibly oil-bearing structures, but large-scale features illustrate the same principles. Since many large features are widely known and have some stimulating relations to known geology, most of the specific examples discussed are taken from a comparison of large-scale, or regional gravity features with regional geology. A regional gravity map of the southwestern United States shows, among others, the following particularly interesting features.

An arcuate band of close gravity contours, running across central Texas, corresponds closely with the Balcones-Mexia-Luling fault complex. The gravitationally positive side is toward the east and south. The faults of the Balcones system, downthrown toward the east and south, are generally toward the bottom of the gravity low or part way up the steep slope. The faults of the Mexia-Luling system, downthrown to the west and north, are generally on the upper slope and near the top of the gravity high; at the north end of the trend they lie east of the gravity high axis.

A strong gravity maximum, extending across southwestern Oklahoma and the Texas panhandle, agrees closely with the Muenster arch-Wichita-Amarillo structural trend.

A regional gravity maximum is in rather close accord with the Central Basin platform of West Texas; strong flanking minima are in fair accord with the Midland basin on the east and the Delaware basin on the west.

On the other hand, there is a strong minimum, with a nearly east-west trend, which extends for 300 miles across north-central Texas; a parallel line of round maxima lies just north of this trend. So far as we know, neither the large minimum nor the strong round maxima correspond with any disturbance of the sedimentary section.

FAULT ZONE

In the vicinity of Waco, Texas, the arcuate band here mentioned consists of a gravity disturbance, having the general character of the effect from a fault, with a relief of about 70 milligals. As a basis for initial speculation about the

possible cause of the gravity feature, we can calculate that its principal part could come from a fault-like contact with a mean depth of 5.5 miles; the thickness, for a density contrast of 0.2 is also about 5.5 miles. A higher density contrast would reduce this thickness. A more detailed study could add some details but the general orders of magnitude of limiting depth and thickness are fixed. To advance the analysis, the geophysicist must become a geologist. What is a reasonable density contrast? What rock types in the depth range required could be responsible for this contrast? What type of movement within the earth's crust could bring this density contrast into being? When, in geologic time, could such movement have occurred and how is it related to the zones of faulting which we know within drilling depths? Some very profound disturbance is clearly indicated by the strong gravity anomaly and the close coincidence in position implies a close causal relation to the fault zone.

It has been suggested that this arcuate disturbance is similar to the island arc of the West Indies. The radius of curvature, about 200 miles, is only a little less. The gravity disturbance in Texas has only about half the relief and the form is quite different; the principal characteristic of the island arc anomaly is a deep gravity minimum or trough.

It may be reasonable to guess that the present gravity feature in Texas is an old Paleozoic(?) anomaly of the island arc type but now considerably modified and reduced in magnitude by further movement and isostatic adjustment since it was originally formed. The approximate coincidence of the Llanoria geosyncline with the arc of faults and the gravity feature may lend support to this guess. We would then guess, further, that the Llanoria geosyncline originated in a "tectogene" similar to that proposed in explanation of the present West Indies island arc, of which only part of the original underlying deep crustal deformation still persists so that a considerably reduced and modified gravity expression is shown at the present time. It is obvious that, in making these speculations, the geophysicist is speculating outside his usual realm and needs the help of his geological associates.

Certain limitations on the dimensions of the geological disturbance such as suggested here can be imposed by analysis of the gravity indications. Within these physical limits there are many geological questions. A congenial and inquiring passing of these questions back and forth from one to the other until an answer satisfactory to the geologist in terms of the general nature of the rocks and processes involved, and satisfactory to the geophysicist in terms of the quantitative restrictions on the magnitude, position, and form of the density contrasts required, should lead to a distinct advance in our understanding of the profound disturbances of the earth's crust which must be responsible for this arcuate gravity feature extending some 500 miles across the middle of Texas.

AMARILLO-WICHITA UPLIFT

A profile across the gravity feature corresponding with this large uplift indicates a gravity relief of approximately 70 milligals and a form which can be

accounted for by an uplifted block, the size estimates of which, again, must be contingent on assumptions as to density contrasts. If we assume that such a block comes substantially to the surface, it would be approximately 20 miles wide and, for a density contrast of, say, 0.25, would have its base at a depth of approximately 5 miles; the depth to the bottom would be more or less than this figure depending on whether the density contrast is less or more than that assumed. A deeper, thicker and narrower block also could be fitted to the observed curve. The possible dimensions of such blocks give certain limits which physical analysis can place on the cause of this feature. To make such estimates useful we must turn to the geologist and ask, what type of rock could produce such contrasts? What densities might be involved? What process raised up this huge block of material? Here again the complete answer requires a passing of facts and assumptions back and forth between geophysicist and geologist until answers compatible with the limits imposed by both can be achieved.

CIRCULAR GRAVITY MAXIMA

Gravity surveys have shown several large circular maxima extending from Texas to Georgia, with gravity relief of 30–60 milligals. Particularly conspicuous examples are the well known Crosbyton high, centering in southeastern Garza County, Texas, a somewhat smaller one, centering in southeastern Knox County, Texas, the Logansport high on the Texas-Louisiana line, the Jackson high centering at Jackson, Mississippi, and two very strong circular maxima in southern Georgia. While they differ considerably in detail, all of these features are of a general nature which could be caused by more or less circular, plug-like density contrasts.

The gravity relief of these features is such that they can hardly have their origin within the sediments because the required mass anomaly is so large that no reasonable assumption as to density contrasts would admit the required volume of anomalous material within the sedimentary section. Therefore we can say that the gravity disturbances must be caused principally by density contrasts within the basement rocks. We can not, on physical evidence alone, determine whether or not there is an accompanying disturbance of the overlying sediments. Therefore the geophysicist, as an unaided physicist, can not tell whether such features are of interest as possible causes of sedimentary structure or not.

The Crosbyton anomaly has been tested by several wells and does not correspond with a large structure. On the other hand, the Jackson high corresponds with an uplift that dominates the structural pattern of several counties in southern Mississippi. The Logansport high apparently has some associated uplift. Is there any geological theory which could have predicted these relations? These circular highs may be of volcanic origin, but we do not know. If they are of volcanic origin, the time of their occurrence would be of prime interest in evaluating their possible effect on overlying sediments. If volcanic materials, such as ash or flows, are known to exist in the sediments around areas where there are pronounced circular gravity highs, may we presume that these highs are caused by

disturbances occurring during the time of the sediments carrying such volcanic material? Is the absence of any volcanic material in the section a criterion by which we could safely ignore this type of anomaly as a possible indication of sedimentary structure? Would we expect a volcano to produce a gravity high, and have test surveys been made over any volcanoes to determine the nature and magnitude of their gravity effects? Are there other processes taking place in the geology of igneous rocks which could produce these strong circular gravity features and if so are there any means of determining the geological time at which such process may have occurred? These are geological questions which are intimately related to the evaluation of this type of geophysical feature, but which are outside the usual field of the geophysicist.

PUZZLING GRAVITY MINIMUM

Through the courtesy of Trinidad Petroleum Development Company, we can consider a particularly impressive example of a local specific geological problem posed by a geophysical result. This is furnished by an extremely sharp, circular, 6-milligal gravity minimum with a diameter of only about 2 miles which was found over an area of mud volcanoes in Trinidad. If the picture were inverted, its size and form would closely resemble those of some of the most intense positive anomalies over shallow cap rock of Gulf Coast salt domes.

Its explanation requires a strong, circular negative density contrast, at shallow depth. If the top of the mass anomaly were close to the surface, it would require a thickness at the center of about 650 feet and a diameter of about $1\frac{1}{2}$ miles for a density contrast of one C.G.S. unit. A lower density contrast would require a greater thickness. A deeper, more plug-like form also could account for the feature. It could hardly be a salt dome such as we know in the Gulf Coast because the required density contrast at shallow depth is too great.

The mud volcanoes are gas seeps which bring up substantial volumes of mud. It was suggested that the minimum represents a pitch lake (the famous Trinidad Pitch Lake at Brighton is in a gravity minimum with about 3 milligals relief) but no pitch or oil is brought up with the gas and mud. How could the mud be brought up through a body of pitch without some of the pitch being brought to the surface? If not pitch, what could make the density contrast? Is the mud of low density, perhaps "gas cut," and in a long vertical pipe with a diameter of around 2,000 to 3,000 feet? What are the other geological possibilities? Here is a new and quite unexpected geophysical picture, which, when explained will almost certainly bring about modification of present theories and a better understanding of mud volcanoes. The next step is a geological one to suggest possibilities within the limits imposed by the physical facts.

CONCLUSION

Probably most geologists and geophysicists, who have looked at broad-scale gravity and magnetic maps, have been tempted to interpret them in terms of broad tectonic features which would have effects on the sedimentary geology and there-

fore would be of interest in oil exploration. Such temptations must be tempered by the quantitative control which the geophysicists can supply and by experience in actual relations between the gravity and tectonic data of the kind which is given by a comparison or superposition of the two kinds of maps. We then find many cases of close coincidence. We also find many cases where strong gravity features, some of which are clearly regional and some relatively local, have no counterpart in the geology that we know. It would be a distinct step if we would discover, through broad geological and geophysical thinking, any criteria which would serve as a basis for distinguishing those geophysical features which arise from disturbances which may have affected the sediments and those which have not.

Such criteria, if we find them, will depend on the quantitative control which can be given by the geophysicists and by the factual control and guessing as to possible sources which must be furnished by geologists, together with an active imagination by both, and a sympathetic consideration of each other's view point. Similarly, in the interpretation of individual local anomalies, the geophysicist can supply certain limits of location, size, and depth, but the geologist must then give his help.

When team work between geologists and geophysicists has reconciled all the known items of data with each other and with reasonable speculations, we may approach much more nearly a picture of the geologic past as reflected in present geophysical and geological facts. In this way we can hope to advance beyond geological and geophysical guesses, and let fact keep our feet on the ground when we are tempted to indulge in flights of uninhibited fancy, for as the poet says:[3]

Ah, what avails the classic bent,
And what the cultured word
Against the undoctored incident
That actually occurred

[3] Rudyard Kipling, "The Benefactors," first stanza.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1161-1197, 8 FIGS.

PALEOZOIC GEOLOGY OF NORTH AND WEST SIDES OF UINTA BASIN, UTAH[1]

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ABSTRACT

The sequence of Paleozoic rocks on the north and west sides of the Uinta Basin ranges in age from Cambrian to Permian. On the west side of the Basin, in the southern part of the Wasatch Mountains, the Paleozoic section is nearly 40,000 feet thick and probably contains the most complete sequence of Carboniferous and Permian rocks in the Rocky Mountain region. This thick section is present only in an overthrust block. North and east of the thrust fault, in the central Wasatch Mountains and the Uinta Mountains is a much thinner section of Paleozoic rocks. The thinner section is only about 8,000 feet thick and apparently large segments of the thick section on the south and west are unrepresented.

Cambrian formations in the Wasatch Mountains include the light brown-weathering Tintic quartzite of Lower Cambrian age, overlain successively by olive-green and brown shale and sandstone and mottled gray limestone of the Lower and Middle Cambrian Ophir formation and the mottled gray limestone of the Middle and possibly Upper Cambrian Maxfield limestone. Locally, the Maxfield is absent at the top of the Cambrian. In the Uinta Mountains, the Cambrian rocks are represented only by a sequence of shale, like that of the Ophir formation with subordinate sandstone. This unit is about 3,000 feet thick near the Duchesne River but decreases in thickness eastward. Fossils from the uppermost beds of the unit near the Duchesne River are of Middle or, more probably, Upper Cambrian age.

A persistent dark gray to nearly white vuggy dolomite 150–265 feet thick in the Wasatch Mountains overlies the Cambrian and is provisionally correlated with the Jefferson dolomite of Devonian age. It may be present in the Uinta Mountains near the Duchesne River, but is not recognized farther east.

The Madison limestone of lower Mississippian age and the Deseret and Humbug formations of upper Mississippian age maintain fairly constant lithologic character along the west and north sides of the Uinta Basin, but the aggregate thickness of the three formations decreases from about 1,800 feet in the Wasatch Mountains to 900 feet or less near Vernal. The dark gray cherty limestone and dolomite of the Madison and Deseret limestones are lithologically similar. Brown-weathering sandstone interbedded with gray cherty limestone characterizes the Humbug formation which commonly shows extensive brecciation. Post-Humbug Mississippian rocks south of the thrust fault in the Wasatch Mountains have an aggregate thickness of about 4,000 feet and include the Great Blue limestone, which consists of black to dark gray thin-bedded limestone with some dark shale, and the greater part of the overlying Manning Canyon shale which consists of dark shale with some dark limestone and gritty sandstone. North of the thrust fault, the post-Humbug Mississippian is represented in the Wasatch Mountains by about 100 feet of dark shale at the base overlain by 400 to 500 feet of dark gray limestone and along the Uinta Mountains mainly by dark shale 100–300 feet thick. This thin shale and limestone unit is tentatively correlated with the basal part of the Great Blue limestone.

Pennsylvanian and Permian rocks in the southern Wasatch Mountains include the uppermost part of the Manning Canyon shale overlain successively by the Oquirrh, Kirkman, Diamond Creek, and Park City formations. The black shale of the Manning Canyon intergrades with the limestone at the base of the Oquirrh formation. The Oquirrh formation, about 25,000 feet thick, is mainly quartzitic sandstone with some interbedded limestone. Fusulinids of Atoka, Des Moines, Missouri, Virgil, and Wolfcamp age are recognized in the Oquirrh. The gray to black thinly laminated limestone of the overlying Kirkman has a maximum thickness of 1,600 feet, but the formation is absent locally. The Diamond Creek sandstone overlying the Kirkman is a gray to buff calcareous to quartzitic cross-bedded sandstone 800–1,000 feet thick, tentatively correlated with the Coconino sandstone. The Park City formation about 1,800 feet thick, consists of three members: an upper and a lower member of light gray cherty limestone with some sandstone separated by a middle black phosphatic shale member. Fossils suggest at least partial equivalence of the lower member with the Kaibab limestone and the remainder of the formation with the Phosphoria formation. This sequence of Pennsylvanian and Permian rocks with a total thickness of nearly 30,000 feet in the southern Wasatch Mountains, is

[1] Read before the Association at Denver, April 28, 1948. Manuscript received, March 12, 1949. Published with permission of the director of the United States Geological Survey.

[2] Geologists, United States Geological Survey.

represented on the opposite side of the thrust fault by about 3,000 feet of strata including the Morgan formation at the base overlain by the Weber and Park City formations. The Morgan from 400 to about 1,400 feet thick, consists of a lower limestone unit and an overlying interbedded gray to red limestone and sandstone unit. The Morgan contains fusulinids of Lampasas or Morrow age in the lower part and of Des Moines age in the upper part, thus indicating correlation with the lower part of the Oquirrh formation. The unfossiliferous Weber sandstone, 1,000–1,500 feet thick, in the Uinta Mountains, is correlated with the Pennsylvanian Weber quartzite of the central Wasatch Mountains and tentatively with a lower part of the Oquirrh formation. A stratigraphic break representing a large part of late Pennsylvanian and early Permian time is inferred between the Weber sandstone and the overlying Park City formation. The lower member of the Park City extends a short distance east of the Duchesne River beyond which the middle phosphatic shale member rests on the Weber sandstone. The upper member varies in thickness and apparently intertongues eastward with red and gray beds lithologically inseparable from the overlying rocks of Triassic age.

Introduction

The Uinta Basin is an irregularly shaped and structurally depressed area in northeastern Utah between the high range of the Uinta Mountains on the north and the Book Cliffs on the south (Fig. 1). The eastern boundary of the Basin is the structurally high area in western Colorado in the vicinity of the Douglas Creek and Rangely anticlines and the Basin extends westward for approximately 150 miles to the Wasatch Mountains, which separate the Uinta Basin from the Great Basin on the west. Almost all the Uinta Basin is within the drainage area of the Green River except the extreme western part which is drained by streams that flow to the Great Basin; and thus, the Uinta Basin includes a small area that, in a geographic sense, could be classed as part of the Great Basin.

The central part of the Uinta Basin is occupied by rocks of Tertiary age to a maximum depth probably in excess of 10,000 feet; they range in age from Paleocene to Miocene or Pliocene. Rocks of pre-Tertiary age crop out around the margin of the Basin in the Uinta and Wasatch mountains, and in the Plateau region of southeastern Utah. Along the north and west margins of the Basin, rocks ranging in age from pre-Cambrian to Cretaceous are exposed. On the south flank of the Basin, the oldest surface rocks are of Pennsylvanian age except for the pre-Cambrian rocks exposed in the Uncompahgre Plateau near the Colorado state line; and relatively little information is available regarding the rocks of pre-Pennsylvanian age in this part of the Basin.

The Paleozoic rocks include formations of Cambrian, Devonian, Carboniferous, and Permian ages with no known representation of the Ordovician and Silurian systems. Notable differences in the sections of Paleozoic rocks occur around the periphery of the Basin, including lithologic differences as well as in the amount of geologic time represented. The most marked differences occur in the upper part of the section, and within a distance of a few miles in the extreme western part of the Basin, as is illustrated in the comparison of the thick western section with the thin eastern section shown in Figure 2. A thrust fault separates the thick section from the thin section in the Wasatch Mountains southwest of Heber, Utah (Fig. 1). The abrupt change in thickness can be explained only by the juxtaposition along the thrust fault of facies originally deposited many miles from each other. Field work has not been completed on the eastern or southern

continuation of the fault beyond the valley in which Heber is located, but it appears to be concealed beneath the Tertiary sediments in the western part of the Uinta Basin in the vicinity of Strawberry Reservoir and probably greatly

FIG. 1.—Index map of northeastern Utah.

modifies the distribution of the Paleozoic sedimentary rocks in that part of the Basin.

The following summary discussion is based primarily on intermittent field work by the writers in different parts of the region and over a period of several years. A. A. Baker mapped the geology of part of the Wasatch Mountains on the

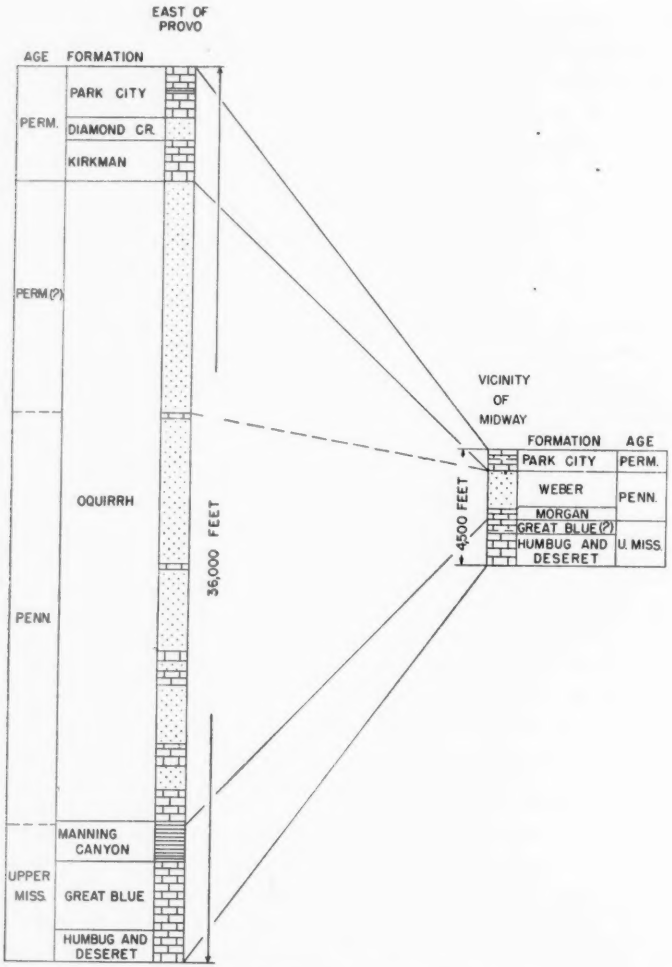

FIG. 2.—Comparison of late Paleozoic sections in adjacent areas in southern Wasatch Mountains.

western margin of the Basin and parts of the Colorado Plateau south of the Basin. J. W. Huddle mapped the geology of a large area on the south flank of the Uinta Mountains, west of the Uinta River, and D. M. Kinney extended the mapping from the Uinta River eastward approximately to the Green River. Additional field work remains to be done, however, to complete the study of the geologic relations of the Paleozoic rocks around the margin of the Uinta Basin.

The interpretation of the change in stratigraphic relations is also dependent in large measure on paleontologic determinations. Studies of numerous collections of fossils made during the field work are in progress by J. Steele Williams and L. G. Henbest, and partial results have been used in the preparation of this discussion. Pending additional field work and further paleontologic studies, however, some of the concepts of the Paleozoic geology of the Uinta Basin must be considered as tentative. Part of the results of the geologic investigations by the writers have been presented in earlier publications.[3]

STRATIGRAPHY

CAMBRIAN SYSTEM

Rocks of Cambrian age crop out at numerous localities in the Wasatch Mountains and along the south flank of the Uinta Mountains. Sections of the Cambrian formations from the Oquirrh Mountains to Diamond Gulch are shown in Figure 3. Angular discordance has been noted at the base of the Cambrian in the Cottonwood-American Fork area,[4] where the Tintic quartzite rests on pre-Cambrian quartzite. At many localities in the Cottonwood district and elsewhere in the Wasatch Mountains, the Tintic quartzite rests on tillite of uncertain age that is now tentatively included in the pre-Cambrian by Calkins.[5] Toward the east the Cambrian rocks rest on the thick quartzite of the Uinta Mountain group which is assigned to the pre-Cambrian. Locally, in the eastern part of the Uinta Mountains, the contact of the quartzite of the Uinta Mountain group with the overlying shale of Cambrian age, appears to be gradational, and possibly some of the quartzite commonly included in the Uinta Mountain group is Cambrian in age. The Cambrian rocks are unconformably overlain in the Wasatch Mountains by the Jefferson(?) dolomite of Devonian age, but toward the east along the south flank of the Uinta Mountains the Jefferson(?) dolomite appears to be absent and the Madison limestone of Mississippian age rests on the Cambrian rocks.

The Cambrian rocks are nearly everywhere divisible into two or more formations, but they vary greatly in lithology across the north side of the Basin. In the Wasatch Mountains, a three-fold division is generally recognized, consisting of the Tintic quartzite at the base overlain successively by the Ophir formation

[3] A. A. Baker, "Stratigraphy of the Wasatch Mountains in the Vicinity of Provo, Utah," *U. S. Geol. Survey Prelim. Chart 30* (1947), Oil and Gas Inves. Ser.

A. A. Baker and J. Steele Williams, "Permian in Parts of Rocky Mountains and Colorado Plateau Regions," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 617–35.

J. W. Huddle and F. T. McCann, "Geologic Map of Duchesne River Area, Wasatch and Duchesne Counties, Utah," *U. S. Geol. Survey Prelim. Map 75* (1947), Oil and Gas Inves. Ser.

———, "Late Paleozoic Rocks Exposed in the Duchesne River Area, Duchesne County, Utah," *U. S. Geol. Survey Cir. 16* (1947).

D. M. Kinney and J. F. Rominger, "Geology of the Whiterocks River-Ashley Creek Area, Uinta County, Utah," *U. S. Geol. Survey Prelim. Map 82* (1947), Oil and Gas Inves. Ser.

[4] F. C. Calkins and B. S. Butler, "Geology and Ore Deposits of the Cottonwood-American Fork Area, Utah," *U. S. Geol. Survey Prof. Paper 201* (1943), pp. 11–12.

[5] F. C. Calkins, personal communication.

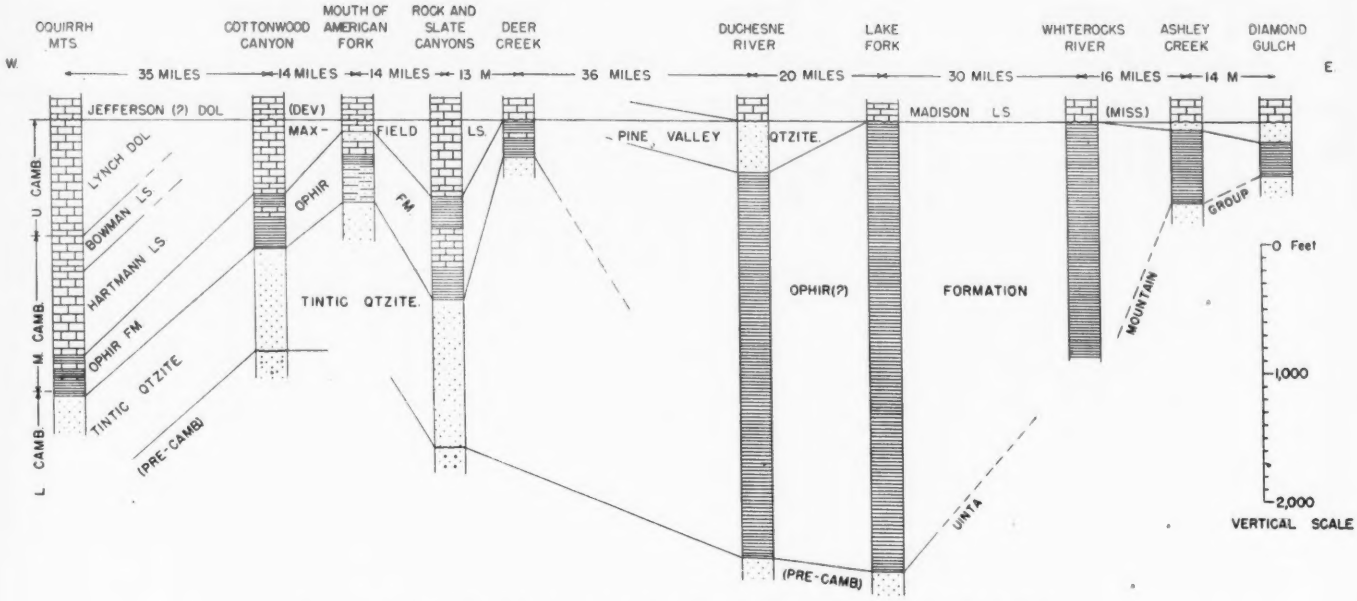

FIG. 3.—Sections of Cambrian formations from Oquirrh Mountains to Diamond Gulch, Utah.

and the Maxfield limestone. The Tintic quartzite is mainly a white, weathering to orange-brown, medium- to coarse-grained, cross-bedded quartzite with a few layers of grit and fine conglomerate. The overlying Ophir formation has a gradational contact with the Tintic quartzite. It is typically olive-green micaceous shale with some interbedded sandstone and ordinarily with a limestone unit that is lithologically similar to the overlying Maxfield limestone. The Maxfield limestone is medium gray to white interbedded limestone and dolomite that is characteristically mottled with yellow, buff, brown, or gray especially noticeable on weathered surfaces. Some beds in the Maxfield show oölitic texture.

In the Cottonwood-American Fork district, the Tintic quartzite is 800 feet thick; the Ophir formation is 420 feet thick with a limestone unit 80 feet thick and 100 feet below the top of the formation; and the Maxfield limestone is 570 feet thick.[6] In the Oquirrh Mountains about 30 miles west of the Cottonwood-American Fork district, Gilluly[7] has described a section which shows a similar three-fold division of the Cambrian rocks. Only the upper 300 feet of the Tintic quartzite are exposed. The Ophir formation is 320 feet thick and consists of gray to greenish gray and brown shale, in part micaceous, and some interbedded mottled limestone. The major difference in the Cambrian rocks from the section in the Wasatch Mountains is an increase in thickness of the calcareous sediments in the upper part of the section. These calcareous rocks are nearly 2,000 feet thick in the Oquirrh Mountains where they are divided into the Hartmann limestone at the base, the Bowman limestone, and at the top, the Lynch dolomite which makes up approximately the upper half of the calcareous sequence.

In the Wasatch Mountains, south of the Cottonwood-American Fork district, near the mouth of American Fork Canyon, and in Deer Creek, only the upper part of the Tintic quartzite is exposed, but the lithologically typical formation is 1,155 feet thick in the Rock Canyon-Slate Canyon area. The Ophir formation in the lower part of American Fork Canyon is 537 feet thick and consists of brown to olive-green micaceous shale with numerous beds of olive-green to brown and reddish sandstone, and a limestone unit 75 feet thick. At Deer Creek the Ophir formation is 288 feet thick and is lithologically comparable with the outcrops in American Fork. A limestone unit is 38 feet thick. In the Rock Canyon-Slate Canyon area, the Ophir is lithologically comparable with outcrops farther north in the Wasatch Mountains but is about 800 feet thick. The Maxfield limestone decreases in thickness from 570 feet in the Cottonwood-American Fork district to 91 feet near the mouth of American Fork. It increases in thickness to 597 feet in Rock Canyon where the upper part—164 feet thick—is mainly a light gray dolomite. At Deer Creek it appears to be absent although there is some possibility of faulting at the latter locality.

The sections of the Cambrian rocks along the south flank of the Uinta Moun-

[6] F. C. Calkins and B. S. Butler, *op. cit.*, p. 10.

[7] James Gilluly, "Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah," *U. S. Geol. Survey Prof. Paper 173* (1932), pp. 7–20.

tains in the vicinity of the Duchesne River, along the Lake Fork, the Whiterocks River, Ashley Creek, and Diamond Gulch bear little lithological resemblance to the Cambrian rocks in the southern Wasatch and Oquirrh mountains. The lithological differences do not represent different facies on opposite sides of the thrust fault near Heber that are comparable with the changes in the later Paleozoic sediments, as the section in the Cottonwood-American Fork district, which fits the pattern of Cambrian sediments farther south in the Wasatch Mountains, is believed to be on the same side of the major thrust as the Uinta Mountains sections. It appears, therefore, that the eastward change in sedimentation reflects a regional change irrespective of any telescoping effect of movement on the thrust fault.

In the vicinity of the Duchesne River the greater part of the Cambrian sequence consists of greenish gray and black micaceous shale, in part glauconitic, and with thin beds of dark yellow brown arkosic sandstone. As measured by Berkey[8] and checked by Forrester[9] the shale is about 3,000 feet thick. A lithologically similar unit about 3,500 feet thick on Lake Fork, probably more than 2,500 feet thick along Uinta River and more than 1,800 feet thick along the Whiterocks River seems unquestionably to be continuous with the deposits along the Duchesne River, and, because of their lithologic similarity, a correlation at least in part with the Ophir formation of the Wasatch Mountains is strongly suggested. East of the Whiterocks River, a tan and reddish brown sandy shale is 563 feet thick on Ashley Creek and 260 feet thick in Diamond Gulch. This shale is probably a thin eastward continuation of the thick shale on the west, and it may be continuous with the Lodore shale of the eastern Uinta Mountains. It is possible, however, that the shale unit on Ashley Creek and Diamond Gulch is a part of the Uinta Mountains group of pre-Cambrian age, and that the thick Cambrian shale of the western section is absent at those localities.

In the vicinity of the Duchesne River the shale unit is overlain with apparent conformity by sandstone about 400 feet thick to which Forrester[10] applied the name Pine Valley quartzite. It consists mainly of massive cross-bedded sandstone. Some of the beds are calcareous and arkosic and a few are quartzitic. The dominant color is light yellow-brown changing to greenish gray in the upper part, and it weathers dark brown with some purple and green mottling. The Pine Valley quartzite is absent locally in the vicinity of the Duchesne and Uinta rivers and is absent on Lake Fork and Whiterocks River. A white pebble conglomerate 63 feet thick overlying the shale unit of Cambrian(?) age, on Ashley Creek and a conglomeratic arkosic sandstone 155 feet thick in Diamond Gulch may be equivalent to the Pine Valley quartzite. About 10 miles east of the

[8] C. P. Berkey, "Stratigraphy of the Uinta Mountains," *Bull. Geol. Soc. America*, Vol. 16 (1905), p. 521.

[9] J. D. Forrester, "Structure of the Uinta Mountains," *ibid.*, Vol. 48 (1947), p. 638.

[10] J. D. Forrester, *op. cit.*, p. 638.

Duchesne River, in the vicinity of Rock Creek, the Cambrian section above the Pine Valley quartzite includes about 150 feet of olive-gray siltstone overlain by 96 feet of white dolomitic limestone, and 36 feet of brown-weathering conglomerate. Elsewhere in the area these rocks have apparently been removed by pre-Mississippian erosion.

Fossils that have been collected from the formations of Cambrian age at numerous localities in the region show the presence of rocks of Lower, Middle, and Upper Cambrian age. The boundaries between these divisions are ill defined, and fossil collections are too sparse or are inadequate for precise correlation of different lithologic facies of the strata. No fossils have been reported from the Tintic quartzite, but fossils of Lower Cambrian age have been found in the lower part of the overlying Ophir formation in the Cottonwood-American Fork district and elsewhere in Utah. Evidence is not available to show whether the Tintic grades laterally into, and is equivalent to, the lower part of the thick shale unit on the Duchesne River, whether it pinches out between the shale and the pre-Cambrian quartzite of the Uinta Mountain group, or whether the Tintic is equivalent to the upper part of the Uinta Mountain group as suggested by Hintze.[11] Although the lower beds of the Ophir formation in the Wasatch Mountains are assigned to the Lower Cambrian, most of the formation on the basis of its fauna is assigned to the Middle Cambrian. At the west, in the Oquirrh Mountains, that part of the limestone sequence, nearly 1,000 feet thick, which overlies the Ophir and is included in the Hartmann and Bowman limestones, is also assigned to the Middle Cambrian, but the overlying Lynch dolomite at the top is probably Upper Cambrian in age. Fossils collected from the lower part of the Maxfield limestone in Rock Canyon are assigned to the Middle Cambrian by Norman Denson. On the basis of the fauna in the Maxfield limestone in the Cottonwood Canyon area, Calkins and Butler regarded the entire Maxfield as probably Middle Cambrian in age. To the east along the south flank of the Uinta Mountains, northeast of Bear Lake in Sec. 13, T. 2 N., R. 7 W., one collection of fossils from greenish gray sandstone is described by Edwin Kirk as containing *Dicellomus* or a similar form of Middle or, more probably of Upper Cambrian age. These fossils were not found in place but probably came from the siltstone above the Pine Valley quartzite. The Pine Valley quartzite was included in the Cambrian by Forrester and the aforementioned fossils apparently confirm that age assignment.

An erosional interval of long duration is indicated by the stratigraphic relations at the top of the Cambrian. In the southern Wasatch Mountains, rocks of Devonian age rest on Cambrian strata, but along the south side of the Uinta Mountains, the Madison limestone of Mississippian age overlies the Cambrian with local angular discordance. Marked erosion at the unconformity is suggested

[11] F. F. Hintze, "The Proterozoic-Paleozoic Contact in the Western Uinta and Central Wasatch Mountains, Utah," *Proc. Utah Acad. Sci.*, Vol. 11 (1934), p. 166.

by the eastward thinning of the upper calcareous sediments, and the absence locally in the Wasatch Mountains, as at Deer Creek, of the limestone of Middle and Upper Cambrian age that elsewhere overlies the Ophir formation.

ORDOVICIAN AND SILURIAN SYSTEMS

No rocks of Ordovician or Silurian age have been recognized on the north and west margins of the Uinta Basin, but they are present in adjacent areas. Ordovician rocks are widespread in occurrence west in the Great Basin and are represented in the Tintic district near Eureka, Utah, by limestone and dolomite about 2,300 feet thick of Lower and Upper Ordovician age, and farther west in western Utah and Nevada the Middle Ordovician is represented by the Eureka quartzite.[12] Similarly in north-central Utah near the northern end of the Wasatch Mountains, a thick series of Ordovician rocks is present and includes in ascending order, the Garden City limestone, 1,900 feet thick, the Swan Peak quartzite, 500 feet thick, both Lower Ordovician in age, and the Fish Haven dolomite 500 feet thick, of Upper Ordovician age.[13] Ordovician rocks are also present east of the Uinta Basin in central Colorado where they include the Manitou limestone, Harding sandstone, and Fremont limestone of Lower, Middle, and Upper Ordovician age, respectively.

Dolomite of Silurian age is widespread in the Great Basin and is present in north-central Utah near the northern end of the Wasatch Mountains where the Laketown dolomite is about 1,000 feet thick. No Silurian rocks are known in Colorado.

Available information regarding the distribution of the Ordovician and Silurian rocks seems to indicate that the area of the Uinta Basin was exposed to erosion following the withdrawal of the Upper Cambrian sea and remained a land area throughout most or all of Ordovician and Silurian time.

DEVONIAN SYSTEM

In the Wasatch Mountains, rocks of Cambrian age are overlain unconformably by rocks provisionally assigned to the Jefferson dolomite of Devonian age. These rocks consist mainly of thin-bedded to thick-bedded medium gray and light gray cliff-forming dolomite commonly characterized by the presence of vugs, 1–2 inches in diameter, that are hollow or partly filled with calcite. A bed of buff to gray calcareous sandstone up to 12 feet thick, in places containing pebbles of quartz up to an inch in diameter, is present at the base of the formation at nearly all outcrops. The Jefferson(?) dolomite is about 150 feet thick in the Cottonwood-American Fork district[14] and 185 feet thick at the west in the Oquirrh

[12] T. B. Nolan, "The Basin and Range Province in Utah, Nevada and California," *U. S. Geol. Survey Prof. Paper 197-D* (1943), p. 151.

[13] G. B. Richardson, "Geology and Mineral Resources of the Randolph Quadrangle, Utah-Wyoming," *U. S. Geol. Survey Bull. 923* (1941), pp. 13–18.

[14] F. C. Calkins and B. S. Butler, *op. cit.*, pp. 20–21.

Mountains.[15] In the Wasatch Mountains south of the area described by Calkins and Butler, the thickness of the formation is 170 feet near the head of American Fork, 186 feet near the mouth of American Fork, and 265 feet in Rock Canyon. At the east on the Duchesne River, 40 feet of light gray dense dolomitic limestone with sandy silty beds that is included in the basal part of the Madison limestone is unlike the overlying Madison and possibly is equivalent to the Jefferson(?) dolomite. Along the Whiterocks River, 15 feet of the rocks included in the basal part of the Madison are thin-bedded, fine- to medium-grained tan to reddish sandstone and sandy shale with a thin bed of dark gray limestone that may conceivably also be a thin clastic facies of the Jefferson(?) dolomite. Eastward from the Whiterocks River along the south flank of the Uinta Mountains, the Madison limestone overlies the Cambrian rocks.

Few fossils have been found in the Jefferson(?) dolomite in the southern Wasatch Mountains and those found are not diagnostic. Correlation with the Jefferson of other parts of northern Utah is based on stratigraphic position and lithologic resemblance. Fossils found in the uppermost part of the rocks here included in the Jefferson(?) in American Fork and Rock Canyon are tentatively considered by J. Steele Williams to be Mississippian in age; therefore, some rocks of Mississippian age may have been included with the Jefferson(?) at those localities. In Colorado, the Ouray limestone and Elbert formation and their approximate equivalent, the Chaffee formation, are Upper Devonian in age and are considered to represent somewhat earlier Upper Devonian than the Jefferson.[16] The Devonian formations of Colorado are not known to extend westward into the Uinta Basin.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SERIES

Most of the great thickness of the dominantly calcareous Paleozoic rocks in the southern Wasatch and Uinta mountains are Mississippian in age. They unconformably overlie rocks of Cambrian or Devonian age, and are overlain by Pennsylvanian formations. The lower part of the Mississippian section including the Madison limestone of lower Mississippian age and the overlying Deseret and Humbug formations of upper Mississippian age is 1,800 feet thick in the southern Wasatch Mountains and decreases in thickness eastward to about 850 feet near Diamond Gulch. The decrease is gradual, and the units persist with more or less uniform lithologic characteristics. The upper part of the Mississippian section, however, shows much greater differences between the two localities. In the Wasatch Mountains near Provo, the Great Blue limestone of upper Mississippian age, and the overlying Manning Canyon shale, which is mainly Mississippian in age, are more than 4,400 feet thick. Farther north in the Wasatch Mountains and

[15] James Gilluly, *op. cit.*, p. 20.

[16] G. A. Cooper and others, "Correlations of the Devonian Sedimentary Formations of North America," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1768–69.

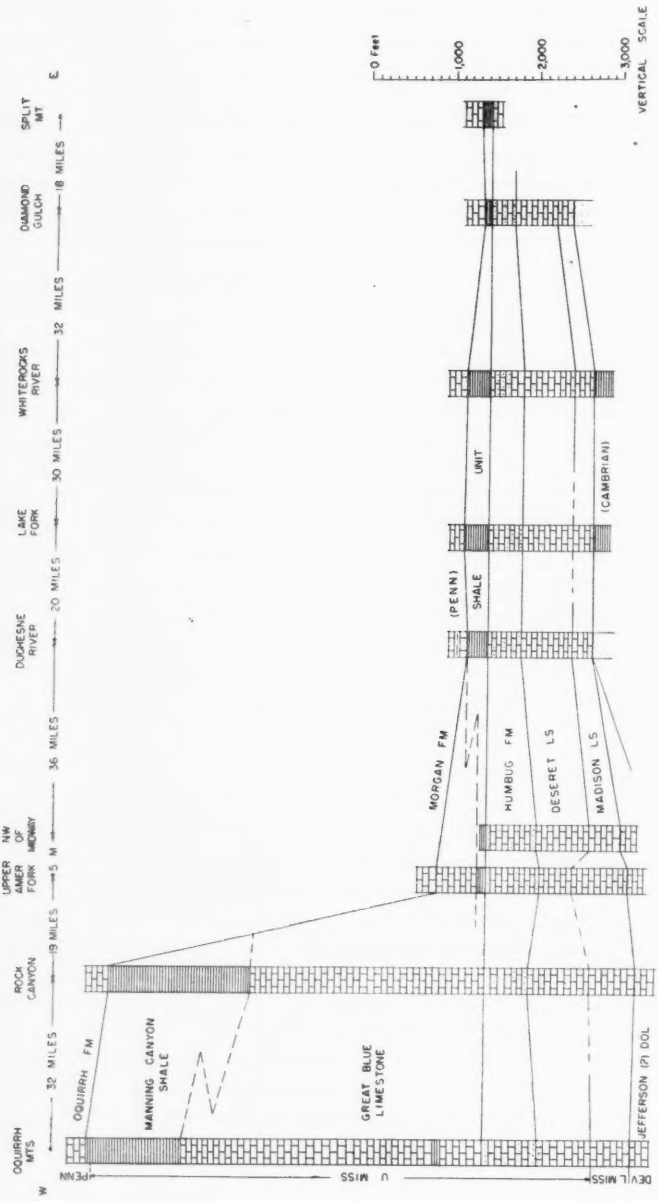

FIG. 4.—Sections of Mississippian rocks from Oquirrh Mountains eastward along Wasatch Mountains and south flank of Uinta Mountains.

along the north side of the Uinta Basin, those formations are either absent or are represented by beds only a few hundred feet thick. The change in thickness is abrupt. According to present information the thicker section is present only in the overriding block of the thrust fault near Heber, and the thin part of the section is restricted to the overridden block. Fossils are abundant in parts of the section and detailed paleontologic studies will probably solve the correlation problems that now exist. Without such studies, however, reliance must be placed upon lithologic differences to distinguish the formations. Gross lithologic features are fairly distinctive for each formation, but in detail similarities exist that cause difficulties in identifying boundaries between formations and in identifying parts of formations in fault blocks where continuity of the section is disrupted. Some of the variations in thicknesses noted by the writers are almost certain to be ascribed to the lack of adequate criteria for selecting contacts; as are different thicknesses for individual units in the same sections as given by other geologists. Sections of the Mississippian rocks in the Oquirrh Mountains, at several localities in the Wasatch Mountains, and along the south flank of the Uinta Mountains are shown in Figure 4.

Madison limestone.—The Madison limestone at the base of the Mississippian sequence maintains fairly uniform lithologic features across the area. It is predominantly cliff-forming, dark to medium gray dense limestone, commonly in part dolomitic, and in large part characterized by thin regular bedding in beds a fraction of a foot thick. Bands and nodules of black and gray chert are abundant locally, and thin beds of dark gray to black shale separate many of the limestone beds. Fossils are extremely abundant in some beds and include brachiopods, gastropods, and corals of lower Mississippian age. Where the Jefferson(?) dolomite underlies the Madison limestone there is a marked contrast between the dark thin-bedded Madison limestone, and the light gray to white dolomite usually found at the top of the Jefferson(?) and the massive beds of the Jefferson(?). At most places the contact appears to be conformable, but unconformable relations have been observed by Gilluly in the Oquirrh Mountains where pebble beds in the base of the Madison rest on karst topography developed on the Jefferson(?). On the Duchesne and Whiterocks rivers the rocks assigned to the Madison, which may include a thin representative of the Jefferson(?) dolomite at the base, rest with angular discordance on shale of Cambrian age, but farther east, angular discordance is not apparent at the unconformity between the Madison and the underlying Cambrian rocks.

A zone of phosphatic oölites commonly associated with a thin black shale unit has been found at several localities in the region and where present is considered to mark the base of the Deseret limestone, which overlies the Madison. This phosphatic unit, on the basis of stratigraphic position and the fauna in the underlying and overlying rocks, appears to be approximately equivalent to a similar unit in the lower part of the Brazer limestone of Mississippian age in the Ran-

dolph Quadrangle in northeastern Utah.[17] The shale zone containing the oölites is 9 feet thick in the Oquirrh Mountains and 17 feet thick in the Wasatch Mountains northwest of Heber. A bed of phosphatic oölites up to 3 inches thick occurs at this horizon at a few localities along American Fork. At places in American Fork, soft pinkish red, sandy, calcareous shale a few feet thick forms a bench at the top of cliff-forming thin-bedded limestone. The reddish zone is not continuous and may not be at the same horizon everywhere, but, at least locally, it coincides with the upper limit of Madison fossils as determined by J. Steele Williams, and it may mark a weathering zone at the contact.

The thickness of the Madison limestone, where the top of the formation is marked by the phosphatic black shale, is 460 feet in the Oquirrh Mountains and 367 feet northwest of Midway. In the Cottonwood-American Fork district, the thickness of the Madison was determined by Calkins and Butler to be 450 feet where it is overlain by a black shale 25 feet thick that apparently is non-phosphatic. Near the mouth of American Fork Canyon 617 feet of cliff-forming thin-bedded limestone below a bed of pinkish red sandy calcareous shale are included in the Madison. In Rock Canyon, a satisfactory boundary for the top of the formation could not be selected, and a thickness of 544 feet has been tentatively assigned to the Madison. Near the head of American Fork, the thickness is given as 660 feet although the upper contact is uncertain. At Deer Creek on the south side of the thrust fault, the thickness is 268 feet, as contrasted with the measurements at the near-by localities on the opposite side of the thrust fault of 660 feet in American Fork Canyon and 367 feet beneath the phosphatic black shale northwest of Heber. Along the south flank of the Uinta Mountains measurements of the thickness of the Madison limestone are 245 feet on the Duchesne River, 231 feet on the Whiterocks River, and 188 feet at Diamond Gulch with the upper contact selected somewhat arbitrarily at the upper limit of the blue-gray, thin-bedded limestone and the lower limit of the more cherty, more massive, limestone and dolomite. As compared with the overlying Deseret limestone, the Madison is characterized by fewer specimens of colonial corals and large horn corals and greater abundance of gastropods belonging to the genus *Euomphalus*.

Deseret limestone.—The type locality of the Deseret limestone is in the Oquirrh Mountains where fossils were collected near the middle of the formation and identified by G. H. Girty[18] as of middle Mississippian age and equivalent to the fauna from the lower part of the Brazer limestone. The Deseret includes the rocks between the Madison limestone and the overlying Humbug formation. The lithologic character of the Deseret shows relatively little change throughout its extent from the type locality through the Wasatch Mountains and along the south flank of the Uinta Mountains. It consists of light to dark gray dense to coarsely crystalline thin- to thick-bedded limestone interbedded with light to

[17] G. B. Richardson, "Geology and Mineral Resources of the Randolph Quadrangle, Utah-Wyoming," *U. S. Geol. Survey Bull. 923* (1941), p. 22.

[18] James Gilluly, *op. cit.*, p. 26.

dark gray dolomite which commonly weathers with a tan granular surface. Chert is abundant in some beds as nodules or lenticular masses along bedding planes and is mainly dark gray, black, or white. Crinoid stems are exceedingly abundant in some beds. Colonial corals are generally the most abundant fossil with some cup corals and brachiopods, but the Deseret is notably less fossiliferous than the underlying Madison. Along the Whiterocks River a limestone breccia 28 feet thick, containing blocks up to 2 feet in diameter, is present at the base of the formation and a few thin beds of reddish limestone are interbedded with the overlying gray limestone and dolomite.

The difficulty in separating the Deseret limestone from the underlying Madison limestone on the basis of their lithologic character has been mentioned in the description of the Madison. The upper contact of the Deseret limestone is placed, by definition, at the base of the lowest thick sandstone or quartzite bed in the overlying Humbug formation. The sandstone beds of the Humbug formation are lenticular, and it is recognized that this arbitrary boundary is not a constant boundary, so that some limestone beds that are included in the Deseret at one locality may be included in the Humbug formation at other localities. The lack of adequate criteria for establishing precise boundaries at both the upper and lower contacts of the Deseret limestone probably accounts for most of the irregularities of measurements of thickness. Measured thicknesses of the rocks included in the Deseret limestone are as follows: 650 feet at the type locality in the Oquirrh Mountains, 733 feet in Rock Canyon, approximately 400 feet near the mouth of American Fork, 900 feet in the Cottonwood-American Fork district, 388 feet near the head of American Fork, 585 feet on Deer Creek, 621 feet near Midway northwest of Heber, where the base is believed to be accurately defined by the presence of phosphatic black shale, 600 to 650 feet on the Duchesne River, 600 feet on the Whiterocks River, and 496 feet north of Diamond Gulch.

A comparison of the combined thicknesses of the Madison and Deseret limestones, which eliminates uncertainties regarding the contact between them, is probably of greater significance in showing the regional trend than the separate measurements. The combined thickness of the two formations in the Wasatch Mountains is nearly twice the thickness of the two formations toward the east near Diamond Gulch. Maximum thicknesses of 1,277 feet and 1,350 feet in Rock Canyon and the Cottonwood-American Fork district, respectively, are comparable with 1,110 feet toward the west in the Oquirrh Mountains and with more or less progressively decreasing thicknesses toward the east of 1,048 feet near the head of American Fork Canyon, 988 feet near Midway, 845 to 895 feet on the Duchesne River, 831 feet on the Whiterocks River, 850 feet on Lake Fork, and 684 feet at Diamond Gulch. The combined measurement of 853 feet at Deer Creek is the only measurement showing notable variation from the general eastward thinning, and this discrepancy may be due to faulting.

Humbug formation.—The Humbug formation conformably overlies the Deseret limestone and the boundary between the two formations is arbitrarily placed

at the base of the lowest bed of sandstone. In the Oquirrh Mountains, and in the Wasatch Mountains, in the vicinity of Provo, the Humbug is overlain with apparent conformity by the Great Blue limestone of upper Mississippian age. In the Wasatch Mountains, north of the thrust fault, the Humbug is overlain by a black shale and limestone unit and eastward along the south flank of the Uinta Mountains it is overlain by a shale unit; these units are Mississippian in age, possibly equivalent to the lower part of the Great Blue limestone. The Humbug formation is differentiated from the other formations included in the thick sequence dominantly composed of limestone, by the presence of numerous beds of sandstone or quartzite that locally make up as much as an estimated 25 or 30 per cent of the formation. The beds of sandstone weather light brown or tan and color the cliffs formed by the Humbug formation to tones distinctive from the gray tones of the other formations. The sandstones are lenticularly bedded, medium- to fine-grained, light gray to buff, and brown, and are in part calcareous and in part quartzitic. They are interbedded with light to dark gray, thin- to thick-bedded, partly dolomitic limestone containing black, brown, white, and red chert in moderate quantities. At nearly all outcrops some of the limestone and sandstone beds are brecciated and recemented, and at places some of the limestone beds show extensive leaching.

Like the underlying formations of Mississippian age the Humbug decreases in thickness to the east with measurements of 600–650 feet in the Oquirrh and Wasatch mountains; and along the Uinta Mountains approximately 400 feet on the Duchesne River, Lake Fork, and the Whiterocks River, and 281 feet north of Diamond Gulch.

Great Blue limestone.—The Great Blue limestone is a thick nearly homogeneous series of thin-bedded, medium- to light gray-weathering, dark gray to black, somewhat cherty limestone which conformably overlies the Humbug formation in the Wasatch Mountains near Provo and at the west in the Oquirrh Mountains. It contains a few beds of dark brown to black shale, which appear to grade laterally into limestone, and a few thin beds of calcareous and quartzitic sandstone. A shale unit 85 feet thick and 500 feet above the base in the Oquirrh Mountains has been designated the Long Trail shale member. A similar shale is partly exposed in Rock Canyon where it is about 675 feet above the base of the formation; the underlying part of the formation which is valley forming may also be mainly shale. At some localities, limestone of the Great Blue rests directly on the Humbug formation, but at other places, a notable thickness of black to brown shale forms the basal unit of the formation. The basal shale, where present, ordinarily includes lenticular masses of rusty- to olive-brown-weathering dense quartzite. The black color on fresh surfaces, light blue-gray color on weathered surfaces, thin regular beds rarely exceeding one foot in thickness, non-magnesian character of the limestone, and pinkish tones on weathered flakes of the limestone are physical characteristics that are generally typical of the Great Blue limestone. The upper part of the formation is well displayed in the canyon walls at the

mouth of Provo Canyon. The thickness of the Great Blue limestone is 2,800 feet in Rock Canyon and 3,600 feet on the west in the Oquirrh Mountains. Fossils from the Great Blue limestone, in the Oquirrh Mountains,[19] described by G. H. Girty and from the Wasatch Mountains examined by J. Steele Williams, clearly establish its upper Mississippian age and its equivalence to part of the Brazer limestone of northern Utah.

A change takes place in the post-Humbug Mississippian section across the zone of thrust faulting through Heber Valley. Near the head of American Fork Canyon dark brown to black shale 100 feet thick overlies the Humbug formation without apparent unconformity and is succeeded by 475 feet of dark gray to black thin-bedded to shaly limestone with abundant black and some brown chert and a few beds of medium to dark gray coarsely crystalline limestone. At a few places a thin bed of grit occurs at the top of this zone of limestone and appears to mark an unconformity between the limestone and the overlying Morgan formation of Pennsylvanian age. A section of shale and limestone comparable in thickness and lithology occurs in Big Cottonwood Canyon[20] where fossils were obtained from the limestone and were assigned to the upper Mississippian by G. H. Girty. These rocks were included in the Humbug formation by Calkins and Butler.[21] A definite correlation of the relatively thin limestone and shale of the sections in upper American Fork and Cottonwood canyons with the much thicker post-Humbug sections farther south in the Wasatch Mountains and in the Oquirrh Mountains on the west has not been established. Lithologically, the post-Humbug rocks in the thin section north of the thrust fault are comparable with the basal part of the Great Blue limestone. Pending the availability of paleontologic evidence bearing on the correlation, the writers are inclined to the opinion that the lower part of the Great Blue limestone is represented north and east of the thrust fault and that later Mississippian rocks are not present. It is possible, however, that the limestone and shale of the American Fork-Cottonwood region are equivalent to some part of the Manning Canyon shale which is of upper Mississippian and Pennsylvanian age, contains much interbedded limestone, and normally overlies the Great Blue limestone.

A shale unit is present between the Mississippian-Humbug formation and the Pennsylvanian Morgan formation in all sections measured along the south flank of the Uinta Mountains. It is 200–300 feet thick on the Duchesne River and Lake Fork where it consists mainly of fissile black shale which becomes gray in the upper part and contains a few thin beds of gray and brown siltstone and limestone. On the Duchesne River, two beds of fossiliferous dark gray limestone 2–15 feet thick divide the shale into three nearly equal parts. The shale unit is 279 feet thick in Whiterocks Canyon, 125 feet thick on Brush Creek, and 80 feet thick north

[19] James Gilluly, *op. cit.*, pp. 30–31.

[20] F. C. Calkins, personal communication.

[21] F. C. Calkins and B. S. Butler, *op. cit.*, p. 27.

of Diamond Gulch. At these localities the shale is black and fissile except for a zone of red sandstone and sandy shale in the basal 25 feet, and it contains a few thin beds of green to black sandstone and thin beds of fossiliferous limestone. A few lignitic shale beds occur near the top of the shale west of the Whiterocks River. At Split Mountain a unit 113 feet thick consisting mainly of shale was measured by McCann, Raman, and Henbest[22] beneath the base of the thick limestone series of the Morgan formation. The shale is poorly exposed at Split Mountain but is described as black carbonaceous shale becoming gray or greenish gray toward the top with interbedded fine-grained, white to yellow, friable, irregularly bedded sandstone and some thin nodular beds of limestone. Plant fossils occur near the middle of the unit. Fossils obtained from the black shale in the Duchesne River area are considered by J. Steele Williams and Helen Duncan to be Brazer (upper Mississippian) in age, and a collection made near the top of the black shale in Sec. 11, T. 2 N., R. 1 W., on Farm Creek in the Whiterocks River area is considered by J. Steele Williams to be Mississippian in age although the specimens are not fully diagnostic. The fossil determinations and stratigraphic position leave little doubt that the shale unit on the Duchesne River is continuous with the shale and limestone unit in the American Fork-Cottonwood area, and detailed mapping along the south flank of the Uinta Mountains establishes with reasonable assurance the continuity of the shale as the topmost unit of the Mississippian as far east as Brush Creek and Diamond Gulch. The shale underlying the thick limestone of the Morgan formation at Split Mountain is considered to be a continuation of the Mississippian shale, although it may be a slightly younger shale. Henbest[23] has expressed the opinion that the shale is Pennsylvanian in age and correlates it with the Molas formation of southwestern Colorado on physical evidence, no fossils from it having been identified. Brill[24] also included these shale beds in the Morgan formation and suggested their correlation with the Belden shale of west-central Colorado which is early Pennsylvanian in age.

MISSISSIPPIAN AND PENNSYLVANIAN SERIES

Manning Canyon shale.—The Manning Canyon shale of upper Mississippian and Pennsylvanian age conformably overlies the Great Blue limestone in the Wasatch Mountains near Provo and at the west in the Oquirrh Mountains. It is not definitely recognized and is believed to be unrepresented in the thinner sections in the Wasatch Mountains north of the thrust fault, and along the south flank of the Uinta Mountains. The Manning Canyon consists of brown to black shale with much interbedded black thin-bedded limestone, and varying amounts

[22] F. T. McCann, N. D. Raman, and L. G. Henbest, "Section of Morgan Formation, Pennsylvanian, at Split Mountain in Dinosaur National Monument, Uintah County, Utah," *U. S. Geol. Survey Mimeographed Release* (1946).

[23] L. G. Henbest in F. T. McCann, N. D. Raman, and L. G. Henbest, *op. cit.*

[24] K. G. Brill, Jr., "Late Paleozoic Stratigraphy, West-Central and Northwestern Colorado," *Bull. Geol. Soc. America*, Vol. 55 (1944), pp. 632–33.

of rusty-weathering quartzite, sandstone, grit, and conglomerate. The thickness of the formation is approximately 1,140 feet in the Oquirrh Mountains and 1,646 feet as measured in Rock Canyon in the Wasatch Mountains. Although the Manning Canyon is about 500 feet thicker in the Wasatch Mountains than in the Oquirrh Mountains, the combined thicknesses of the Manning Canyon and the Great Blue limestone is 300 feet greater in the Oquirrh Mountains than in the Wasatch Mountains. This fact, considered in connection with the apparent lateral gradation from limestone to shale in the Great Blue and the lithologic similarity of the shale and limestone in the two formations, suggests that the contact between them is a facies contact which may be at different stratigraphic positions in different areas.

Fossils are abundant in some parts of the Manning Canyon shale, and, as determined by G. H. Girty from collections in the Oquirrh Mountains,[25] the boundary between the Mississippian and the Pennsylvanian occurs in the upper part of the formation. It is assumed that the upper part of the Manning Canyon shale in the Wasatch Mountains is also of Pennsylvanian age although paleontologic evidence to support the age assignment is not now available. The presence of coarse clastic sediments in the Manning Canyon shale, especially in the Wasatch Mountains, suggests discontinuity of deposition, but evidence is lacking to show unconformity between the Mississippian and Pennsylvanian parts of the formation.

PENNSYLVANIAN SERIES

The rocks of Pennsylvanian age on the west side of the Uinta Basin, in the Wasatch Mountains, are markedly different from the Pennsylvanian rocks on the north side of the Basin that crop out along the south flank of the Uinta Mountains. As with the upper Mississippian and the Permian, notable changes in the section occur at the thrust fault through Heber Valley. Lithologic differences between the rocks on the opposite sides of the thrust fault have resulted in the application of different formation names, and it is only through comparison of faunas that the relations between the two sections can be established. In the Uinta Mountains and in the Wasatch Mountains north of the thrust fault the Pennsylvanian rocks are divided into the Morgan formation and the overlying Weber quartzite or sandstone; in the Wasatch Mountains near Provo south of the thrust fault, an enormously thick section appears to represent a much greater part of Pennsylvanian time and consists mainly of clastic sediments that are included in the Oquirrh formation and in the upper part of the Manning Canyon shale. Sections of the Pennsylvanian rocks from Cottonwood Canyon in the Wasatch Mountains eastward along the south flank of the Uinta Mountains are shown in Figure 5, and a section of the Oquirrh formation near Provo is shown in Figure 6.

Morgan formation.—The name Morgan formation as applied in this paper

[25] James Gilluly, *op. cit.*, pp. 33 and 34.

along the northern margin of the Uinta Basin includes the rocks between the underlying black shale unit of Mississippian age, which is correlated with the lower part of the Great Blue limestone, and the overlying Weber sandstone. The Morgan formation is divided into a lower member consisting mainly of limestone, and an upper member consisting mainly of sandstone with thin beds of limestone. As thus applied, the usage of the term differs from the usage in several recent publications. The lower member at Split Mountain was designated the middle member of the Morgan by Thomas, McCann, and Raman,[26] who included the underlying black shale with older beds in a lower member.

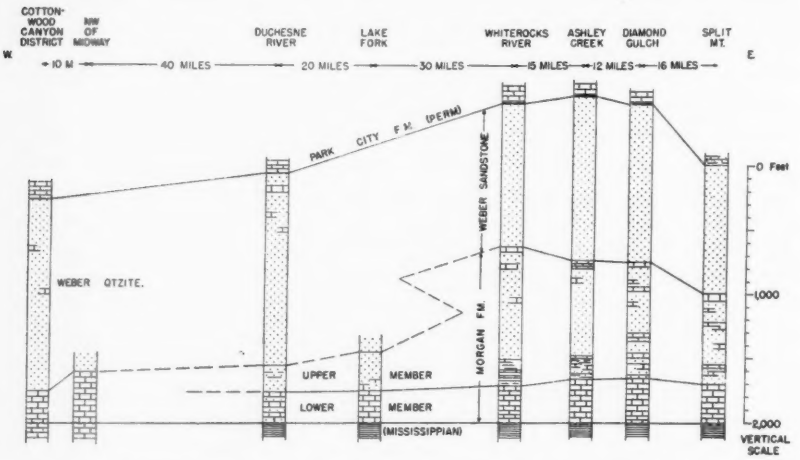

FIG. 5.—Sections of Pennsylvanian rocks from Cottonwood Canyon district to Split Mountain.

Similarly McCann, Raman, and Henbest[27] included the underlying black shale in a lower member of the Morgan with about 50 feet of still older sandstone and applied the term middle member to the limestone here designated the lower unit. J. Stewart Williams[28] appears to have restricted the Morgan to part or all of the sandstone and intercalated limestone of the upper member of this paper and to have included the lower member and locally some of the upper member in

[26] C. R. Thomas, F. T. McCann, and N. D. Raman, "Mesozoic and Paleozoic Stratigraphy in Northwestern Colorado and Northeastern Utah," *U. S. Geol. Survey Prelim. Chart 16* (1945), Oil and Gas Inves. Ser.

[27] F. T. McCann, N. D. Raman, and L. G. Henbest, "Section of Morgan Formation, Pennsylvanian, at Split Mountain in Dinosaur National Monument, Uintah County, Utah," *U. S. Geol. Survey Mimeographed Release* (1946).

[28] J. Stewart Williams, "Carboniferous Formations of the Uinta and Northern Wasatch Mountains, Utah," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 602–07.

the Brazer limestone. Thompson[29] accepted J. Stewart Williams' identification of the Morgan, but recognized a fauna of Pennsylvanian age in rocks designated by Williams as the upper part of the Brazer limestone. Thompson, therefore, abandoned the formation name Morgan in the Uinta Mountains, and extended the name Belden from west-central Colorado[30] to include the lower limestone member of the Morgan formation as used here. Thompson further introduced the names Hell's Canyon and Youghall formations for lower and upper divisions, respectively, of the sandstone with intercalated limestone that is here grouped in the upper part of the Morgan.

The lower member of the Morgan formation at outcrops between the Duchesne River and Split Mountain rests on a shale unit that is at least in part Mississippian. The shale is generally poorly exposed, and little information is available about the nature of the contact. There is no physical evidence of unconformity but, inasmuch as the Mississippian shale is considered to be correlative with the lower part of the Great Blue limestone which is well below the top of the Mississippian, it is inferred that a stratigraphic break of considerable magnitude occurs at the base of the Morgan formation.

The limestone comprising the lower member of the Morgan formation is thin-bedded to massive, medium to light gray, finely crystalline, and in part dolomitic. Some beds contain abundant chert which is gray, white, or red. Thin beds of gray to red shale, and light gray sandstone and siltstone are interbedded with the limestone. The thickness of the unit along the south side of the Uinta Mountains averages about 300 feet and ranges from 240 feet on the Duchesne River to 348 feet north of Diamond Gulch. Henbest[31] has studied fusulinids collected from the limestone at Split Mountain and localities farther east, and he considers them to be early Pennsylvanian Lampasas and Morrow(?) in age. Thompson[32] considers that the fusulinids indicate an early Pennsylvanian Morrow age for the limestone.

The upper member of the Morgan consists of fine-grained, gray, buff, and red, thin-bedded to massive, in part cross-bedded, calcareous sandstone interbedded with a subordinate amount of medium to dark gray and purplish gray, massive to thin-bedded limestone with reddish chert and red sandy shale. Westward the limestone decreases in abundance and very little limestone is present at outcrops on the Duchesne River where the member consists mainly of fine-grained sandstone, siltstone, and mudstone, mainly dark reddish brown and purple with

[29] M. L. Thompson, "Pennsylvanian Rocks and Fusulinids of East Utah and Northwest Colorado Correlated with Kansas Section," *Kansas Geol. Survey Bull. 60*, Pt. 2 (1945), pp. 22–25.

[30] K. G. Brill, Jr., "Late Paleozoic Stratigraphy, West-Central and Northwestern Colorado," *Bull. Geol. Soc. America*, Vol. 55 (1944), pp. 624–27.

[31] L. G. Henbest, quoted by C. R. Thomas, F. T. McCann, and N. D. Raman, "Mesozoic and Paleozoic Stratigraphy in Northwestern Colorado and Northeastern Utah," *U. S. Geol. Survey Prelim. Chart 16* (1945), Oil and Gas Inves. Ser.

[32] M. L. Thompson, *op. cit.*, p. 24.

mottling of gray and green. Measured thicknesses of the upper member are 711 feet at Split Mountain, 907 feet at Diamond Gulch, 798 feet on Ashley Creek, 1,084 feet on the Whiterocks River, 300 feet at Lake Fork, and 205 feet on the Duchesne River. At its upper contact the Morgan appears to be gradational with the overlying Weber sandstone, and the contact is selected arbitrarily. At the Whiterocks River and localities farther east, the contact is placed at the uppermost limestone bed and at the base of sandstone lithologically similar to the typical Weber. Thus part of the rocks included in the Morgan formation at eastern localities are probably the lateral equivalent of rocks included in the Weber near the Duchesne River. At Lake Fork and at Duchesne River limestone beds occur in the upper part of the Weber and the upper contact of the Morgan is placed at the top of the red sandstone. Abundant fusulinids have been collected from the limestone beds in the upper part of the Morgan. Henbest considers them to be Pennsylvanian in age, ranging from early to middle or upper Des Moines. Thompson ascribes a Des Moines or slightly older age to the fusulinids from this unit.

West of the Duchesne River the Morgan formation is represented northwest of Midway and in the upper part of American Fork by limestone 400 feet thick and in the Cottonwood Canyon region, by limestone about 254 feet thick. The limestone is medium to coarsely crystalline, light to medium gray, contains black, white, and orange-red chert, and includes a few thin beds of cross-bedded buff to gray sandstone. It rests on gray to black limestone provisionally correlated with the Great Blue limestone, and the contact is marked locally by a very thin bed of quartz and limestone-pebble conglomerate. The Weber quartzite overlies the Morgan limestone with a sharp lithologic contact, and the upper member of the Morgan of the Uinta Mountains is unrecognized although it may be represented by some part of the Weber quartzite.

Weber sandstone.—In the Uinta Mountains, the Weber sandstone overlies the Morgan formation with a gradational contact. In the eastern sections it is a fine- to medium-grained, gray to light buff and weathering light gray to brown, massive, friable sandstone with prominent cross-bedding. The cross-bedding is less pronounced toward the west, and on the Duchesne River the sandstone is mainly fine-grained, gray, and white, weathering buff, with only small-scale local cross-bedding. Much of this sandstone is calcareous and silty. At western localities it contains a few beds of limestone and dolomitic limestone that are thin-bedded, light gray to dove-colored, cherty, and contain some crinoid stems and other fossils. In the Wasatch Mountains, the sandstone is similar in color and grain size but is quartzitic and contains a subordinate amount of friable sandstone. Interbedded with the quartzite are a few beds of medium to dark gray cherty limestone. The thickness of the Weber increases westward from 1,000 feet at Split Mountain to about 1,500 feet on the Duchesne River, in the Wasatch Mountains northwest of Midway, and in the Cottonwood Canyon area.

Fossils collected by J. Stewart Williams from the Weber sandstone, near its

contact with the underlying Morgan, on Duchesne River were identified by him as early Pennsylvanian in age.[33] The Weber quartzite northwest of Midway contains an early Pennsylvanian fauna. The established early Pennsylvanian age of the Morgan formation and the Weber quartzite, and the apparently gradational and perhaps intertonguing relationships of the Weber and Morgan formations suggest that, at least, the lower part of the Weber sandstone of eastern localities is of early Pennsylvanian age, and it is possible that no part of the formation is younger than Des Moines. Without convincing evidence, the possibility must be recognized, however, that the Weber sandstone is younger than Des Moines and may be either late Pennsylvanian in age, or as has been suggested by several geologists, may be equivalent to the Permian Diamond Creek sandstone.

Manning Canyon shale.—The Manning Canyon shale is mainly of upper Mississippian age but the highest beds are Pennsylvanian in age according to paleontologic studies of fossil collections from the Oquirrh Mountains. Information is not available at present regarding the exact position of the boundary between Mississippian and Pennsylvanian in the Wasatch Mountains. The upper part of the Manning Canyon shale near the Provo River is chiefly black shale and shaly limestone with interbedded brown-weathering sandy shale and abundant beds of greenish quartzitic sandstone and light brown, highly cross-bedded quartzite. The contact with the limestone at the base of the overlying Oquirrh formation is not sharply defined, and deposition appears to have been uninterrupted. The contact is placed arbitrarily at the approximate position of the change from dominant shale below to dominant limestone above. Shale that could be definitely assigned to the Manning Canyon shale is restricted to the south and west side of the thrust fault through Heber Valley. On the opposite side of the thrust the Manning Canyon is unrepresented farther north in the Wasatch Mountains or eastward along the Uinta Mountains unless the thin black shale unit beneath the Morgan formation is in part its equivalent.

CARBONIFEROUS AND PERMIAN(?) SYSTEMS

PENNSYLVANIAN AND PERMIAN(?)

Oquirrh formation.—The name Oquirrh formation is applied to a tremendous thickness of dominantly clastic rocks that overlies the Manning Canyon shale. The formation includes most of the surface rocks in the Wasatch Mountains near Provo (Fig. 6). Although lithologically similar to the Morgan and Weber formations and in part equivalent to them, the Oquirrh represents a much greater part of Pennsylvanian time and may represent essentially continuous sedimentation from early Pennsylvanian through early Permian time. The most complete stratigraphic section is confined to the upper plate of the major thrust fault through Heber Valley, and usage of the name Oquirrh is at present confined to

[33] J. Stewart Williams, "Carboniferous Formations of the Uinta and Northern Wasatch Mountains, Utah," *Bull. Geol. Soc. America*, Vol. 54 (1943), p. 615.

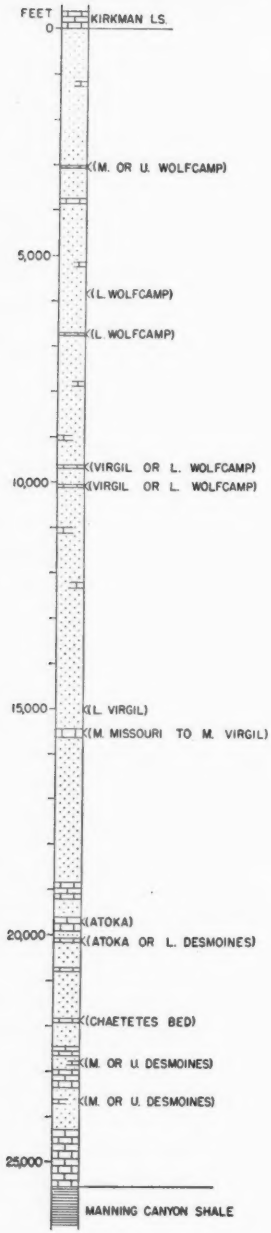

FIG. 6.—Oquirrh formation near Provo, Utah, showing age designations based on fusulinids.

the region south and west of the fault including outcrops in the Wasatch Mountains south of American Fork, the Oquirrh Mountains, and other near-by mountains in the eastern part of the Great Basin.

The basal unit of the Oquirrh formation is a cliff-forming unit consisting mainly of limestone and is 1,245 feet thick. The limestone is medium to dark gray, fine- to coarse-grained, thin- to thick-bedded, with interbedded thin beds of dark gray to black shale, and a few lenticular beds of sandstone. Above the basal limestone unit, the formation consists mainly of fine- to coarse-grained, thin- to thick-bedded sandstone which is gray to buff and weathers brown. Almost all of this sandstone is quartzitic at the surface, but in fresh exposures it generally contains abundant calcareous cement. Dark gray cherty limestone in zones up to several hundred feet thick is interbedded with the sandstone. Fusulinids and other fossils are abundant in the formation mainly in the limestone beds, and locally one bed of limestone about 2,300 feet above the top of the basal limestone unit contains abundant corals of the genus *Chaetetes*.

An accurate section of the Oquirrh formation has not been measured but preliminary measurements indicate a total thickness of about 26,000 feet. Because of structural complexities in the great mass of nearly homogeneous rocks, some uncertainties are involved in the preliminary measurements. Partial study of numerous collections of fusulinids by L. G. Henbest suggests inversion of strata in the lower part of the measured section although in general, as shown on Figure 6, it seems to indicate an orderly succession of time zones, and the measurement of 26,000 feet is believed to be of the correct order of magnitude.

Abundant megafossils in the basal limestone unit, which also contains the fusulinid *Millerella*, are early Pennsylvanian in age. Other collections of fusulinids from above the basal limestone unit are assigned ages ranging through the Pennsylvanian (from Atoka through Des Moines, Missouri, and Virgil) to Permian(?) (Wolfcamp) with forms of Wolfcamp age distributed through the upper 8,000 feet of the formation. The paleontologic evidence thus indicates that the Morgan formation and Weber quartzite of lower Pennsylvanian age (Des Moines or older) is equivalent to only the lower part of the Oquirrh formation. Similarly the available paleontologic evidence indicates that most or all of the Hermosa formation of southwestern Colorado and southeastern Utah south of the Uinta Basin is of early Pennsylvanian age (Des Moines or older)[34] and thus equivalent to only the lower part of the Oquirrh formation.

PERMIAN SYSTEM

The Permian formations, like the underlying Carboniferous formations show marked differences in thickness and lithologic character on opposite sides of the thrust fault through Heber Valley. With the Permian rocks, as with the

[34] N. W. Bass, "Paleozoic Stratigraphy as Revealed by Deep Wells in Parts of Southwestern Colorado, Northwestern New Mexico, Northeastern Arizona and Southeastern Utah," *U. S. Geol. Survey Prelim. Chart 7* (1944), Oil and Gas Inves. Ser.

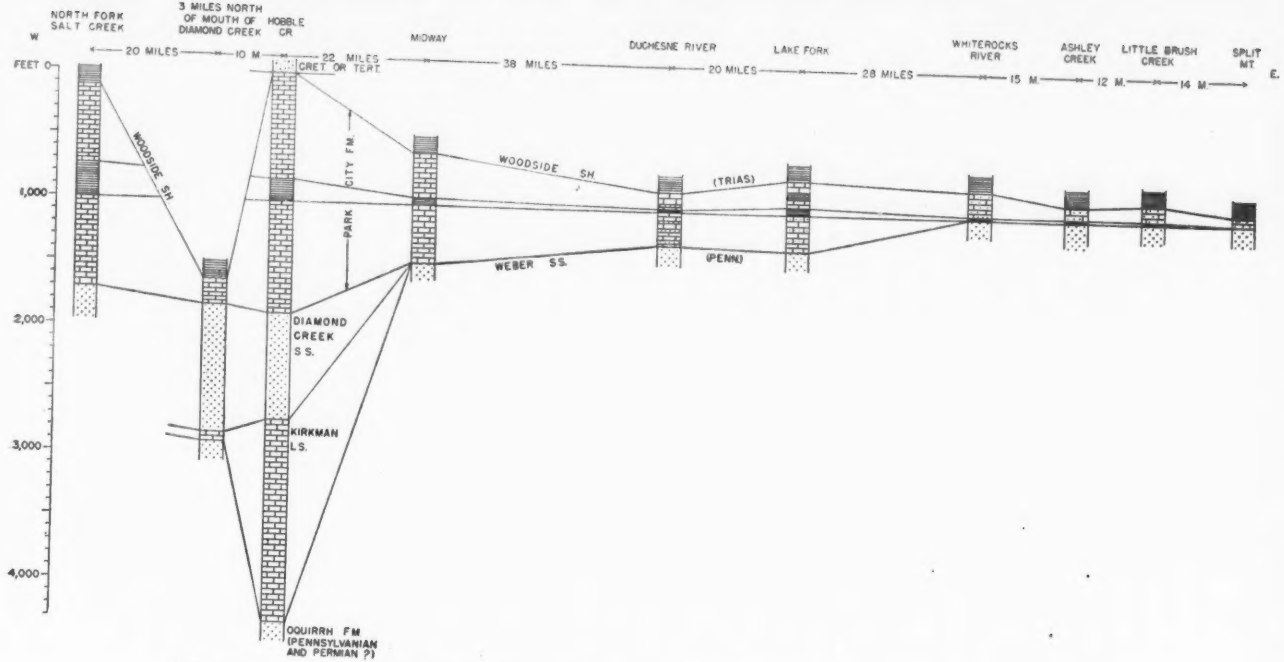

FIG. 7.—Section of Permian rocks in southern Wasatch Mountains and along south flank of Uinta Mountains.

Carboniferous rocks, the time represented by the thicker section in the Wasatch Mountains in the vicinity of Provo constitutes a greater proportion of the geologic period than the attenuated section farther north in the Wasatch Mountains and toward the east in the Uinta Mountains. Most of the available information regarding the Permian formations has been summarized in relatively recent publications. Baker and Williams[35] have described the Permian rocks in the southern Wasatch Mountains and their relationships to the Permian rocks of the Colorado Plateau and the northern Rocky Mountains. The stratigraphic relationships of Permian formations from the Wasatch Mountains eastward along the Uinta Mountains have been discussed by Williams[36] and by Thomas and Krueger.[37] Sections of the Permian rocks in the southern Wasatch Mountains and on the south flank of the Uinta Mountains are shown in Figure 7.

The formations of Permian age in the southern Wasatch Mountains include the Kirkman limestone at the base overlain successively by the Diamond Creek sandstone and the Park City formation. The Kirkman limestone is gray to black, in part finely laminated, fetid limestone that commonly is a recemented breccia of small angular fragments of the laminated limestone. Locally, it contains a small amount of phosphatic oölites. The Kirkman limestone has a maximum thickness of 1,590 feet, measured in the Right Fork of Hobble Creek, and it is 1,350 feet thick in the Left Fork of Hobble Creek. It decreases in thickness markedly toward the south and is absent locally between Hobble Creek and Spanish Fork. It is as much as 75 feet thick in the vicinity of Spanish Fork but its extent south of Spanish Fork is not known. Some beds in the Kirkman limestone are abundantly fossiliferous but preliminary study of the fauna has not yielded information adequate for a precise age determination. It is assigned to the Permian with confidence, however, because of the Wolfcamp age of fusulinids from the upper part of the underlying Oquirrh formation and because the Kirkman appears to grade laterally and vertically into the overlying Diamond Creek sandstone which is inferred to be continuous with the Permian Coconino sandstone of the Colorado Plateau. The Kirkman limestone may be unconformable on the Oquirrh formation for the following reasons: there is a sharp lithologic break at the contact, the basal unit of the Kirkman at many localities is a breccia of angular fragments of quartzite cemented in a sandy calcareous matrix, and the great variation in thickness of the Kirkman suggests that it was deposited upon a surface of considerable relief.

The Diamond Creek sandstone overlies the Kirkman limestone with a gradational contact. It is gray or buff to red, fine- to coarse-grained, cross-bedded,

[35] A. A. Baker and J. Steele Williams, "Permian in Parts of Rocky Mountain and Colorado Plateau Regions," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 619–35.

[36] J. Stewart Williams, " 'Park City' Beds on Southwest Flank of Uinta Mountains, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 82–100.

[37] H. D. Thomas and M. L. Krueger, "Late Paleozoic and Early Mesozoic Stratigraphy of Uinta Mountains, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1255–93.

in large part calcareously cemented and friable, but locally has a siliceous cement. Here and there thin limestone beds are interbedded with the sandstone. The Diamond Creek sandstone in part resembles the quartzitic sandstone of the Oquirrh, and, where the intervening Kirkman limestone is absent, the two formations may not be readily separable. The sandstone is 835–1,000 feet thick between Hobble Creek and Spanish Fork. Poorly exposed red to gray, calcareous and quartzitic, fine- to medium-grained sandstone with some shale in the North Fork of Salt Creek east of Mt. Nebo at the southern end of the Wasatch Mountains is believed to be the Diamond Creek sandstone, but only 250 feet of the sandstone are exposed adjacent to a fault. The Diamond Creek sandstone underlies the Park City formation which is a partial correlative of the Kaibab limestone. On the basis of its stratigraphic position the Diamond Creek sandstone is provisionally correlated with the lithologically similar Coconino sandstone which is 685 feet thick in the San Rafael Swell.

The Park City formation, the uppermost Permian formation in the southern Wasatch Mountains, is divided into three members. The lower member in the Hobble Creek area is thin- to thick-bedded, gray to pinkish gray limestone with gray to white chert and interbedded gray sandy limestone and calcareous sandstone. It is 883 feet thick in the Right Fork of Hobble Creek and 613 feet thick in the Left Fork of Hobble Creek. Southward it is bevelled beneath the unconformity at the top of the Permian, and only the lower 200 feet of the member is preserved in the vicinity of Spanish Fork. Still farther south in the North Fork of Salt Creek, 700 feet of beds consisting of light to medium gray and pinkish, silty and sandy, in part cherty limestone, which is partly an agglomerate of breccia fragments and contains a few thin beds of red siltstone near the base, is correlated with the lower member of the Park City. The fauna of the lower member of the Park City in the Hobble Creek area locally contains abundant specimens of the Kaibab productid *Dictyoclostus ivesi* (Newberry) s. l. as well as some elements of the Phosphoria fauna which suggests that the lower member of the Park City is in part equivalent to the Kaibab limestone of the Colorado Plateau.[38] The Kaibab limestone crops out in the San Rafael Swell where its maximum thickness is about 100 feet, but it is absent locally. The Kaibab limestone thins eastward in southern Utah by lateral gradation to sandstone of the Coconino, and at its outcrops in the San Rafael Swell the limestone is believed to represent a late stage of the Kaibab sea and deposition near the eastern margin of that sea.[39] It may correlate, therefore, with a part of the lower Park City formation well above the base of the member.

The middle member of the Park City formation in the Hobble Creek area is mostly black shale, but contains thin beds of black cherty limestone, grayish sandy limestone and oölitic phosphate. It is about 200 feet thick in Hobble Creek

[38] A. A. Baker and J. Steele Williams, *op. cit.*, p. 624.

[39] A. A. Baker, "Geology of the Green River Desert-Cataract Canyon Region, Emery, Wayne, and Garfield Counties, Utah," *U. S. Geol. Survey Bull. 951* (1946), pp. 52–53.

but is absent near Spanish Fork where pre-Triassic erosion removed all but the lower 200 feet of the lower member of the Park City. Farther south in the North Fork of Salt Creek a middle unit of the rocks there correlated with the Park City formation is the probable equivalent of the middle phosphatic shale member of the Hobble Creek area. This middle unit on the North Fork of Salt Creek consists of interbedded black shale, black, shaly, brown-weathering limestone with abundant black chert and some brown-weathering sandy limestone 268 feet thick. No phosphate was observed in this zone.

The upper member of the Park City formation is overlain unconformably by the Price River formation of Upper Cretaceous age in the Hobble Creek area. Incomplete measurements of the upper member are 830 feet in the Right Fork and 615 feet thick in the Left Fork of Hobble Creek. The upper member of the Park City formation resembles the lower member in lithology as it is composed mainly of thin- to thick-bedded, cherty gray to pink limestone with some interbedded gray sandstone; a thin bed of red shale and siltstone occurs near the top of the upper member at some localities. The upper limestone and the middle shale members of the Park City contain the fauna of the Phosphoria formation including *Punctospirifer pulcher* (*Spiriferina pulchra*) (Meek), *Spirifer pseudocameratus* Girty, and other characteristic species. On the North Fork of Salt Creek above the black shale and limestone unit, the rocks that are believed to be equivalent to the upper member of the Park City formation are buff to gray, in part pinkish limestone and sandy limestone with abundant white chert in some beds and with some interbedded brown-weathering black limestone containing abundant black chert. The thickness of the upper member at this locality is 615 feet. An unconformity between the Permian and the overlying Triassic rocks is clearly evident between Hobble Creek and Spanish Fork where pre-Triassic erosion has removed most of the Park City formation and the thin series of red shale and siltstone of the Woodside shale bevels across the eroded edges of the Park City strata with marked angular discordance. Available information indicates that the unconformable relations of the Permian and Triassic beds extends into the Colorado Plateau and that a substantial part of Park City time is unrepresented between the Kaibab and Moenkopi formations.

In contrast with the Permian section above the Oquirrh formation in the southern Wasatch Mountains, which has an aggregate maximum thickness of more than 4,000 feet in the Hobble Creek area, the Permian section above the Weber sandstone near Midway on the opposite side of the thrust fault is 870 feet thick. The Permian rocks are well exposed in Faucett Canyon west of Midway where the Park City formation rests on the Weber quartzite. The Diamond Creek sandstone and Kirkman limestone that underlie the Park City formation in the Hobble Creek area are unrepresented. Faucett Canyon is less than 10 miles south of the type locality of the Park City formation in Cottonwood Canyon[40] with

[40] J. M. Boutwell, "Geology and Ore Deposits of the Park City District, Utah," *U. S. Geol. Survey Prof. Paper 77* (1912), p. 50.

almost continuous outcrops between the two localities. The section in Faucett Canyon is comparable in thickness and lithologic character with the type section and is believed to be the approximate equivalent of it.

Three divisions of the Park City formation are recognized in Faucett Canyon and, as in the Hobble Creek area, the upper and lower members are mainly limestone with a middle member consisting of phosphatic black shale. The lower member, 458 feet thick, is light gray to buff, fine to coarsely crystalline limestone, with some black, gray, and white chert, interbedded with gray to brown, fine- to coarse-grained, limy sandstone and some gray shale. The zone of phosphatic black shale is 60 feet thick. The upper member of the formation is 352 feet thick and consists of light gray to buff sandy limestone with abundant white chert in some beds and is in part a recemented breccia. Gray to buff calcareous sandstone is interbedded with the limestone but is less abundant than in the lower part of the formation. Eastward along the Uinta Mountains the Park City formation becomes thinner. On the Duchesne River, the lower member, about 270 feet thick, is fine-grained, calcareous, gray to white sandstone that weathers to cavernous light yellow to buff rock interbedded with dense, light to dark gray, dolomitic limestone containing nodules of gray to black chert. Most of the beds are a recemented breccia. The lower member extends only a short distance east of Lake Fork and is absent farther east along the south flank of the Uinta Mountains, where the middle shale member rests on the Weber sandstone. The middle shale member is about 40 feet thick on Blind Stream, a tributary of the Duchesne River, 62 feet thick on Lake Fork, and about 20 feet thick on the Whiterocks River, Ashley Creek, and Brush Creek but is unrecognizable at Split Mountain. The middle shale member on the Duchesne River consists of black phosphatic shale interbedded with gray and greenish gray shale and thin beds of light to dark gray cherty limestone. The characteristic dark color of the shale member is missing at the Whiterocks River and localities farther east and the phosphatic shale is greenish gray. The upper member of the Park City is somewhat irregular in thickness along the south flank of the Uinta Mountains as shown by measurements of 150 feet on the Duchesne River, 200 feet at Lake Fork and Whiterocks River, 97 feet at Red Mountain near Ashley Creek, 199 feet on Little Brush Creek, and 69 feet at Split Mountain. Variations in thickness as well as differences from recorded measurements by other geologists at some of these localities are probably due to the indefinite character of the upper boundary which results from the intertonguing of the upper part of the member with red shale, siltstone, and sandstone inseparable from the overlying Triassic redbeds as described by Williams[41] and by Thomas and Krueger.[42] The upper member in the western

[41] J. Stewart Williams, " 'Park City' Beds on Southwest Flank of Uinta Mountains, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 82–100.

[42] H. D. Thomas and M. L. Krueger, "Late Paleozoic and Early Mesozoic Stratigraphy of Uinta Mountains, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1255–93.

localities is mainly sandy and silty, light gray to yellow; thin- to thick-bedded limestone with abundant white chert, but eastward the limestone becomes more sandy and changes to sandstone, sandy shale, and siltstone with subordinate limestone at eastern localities.

The Permian age of the middle phosphatic shale member and of the upper limestone member of the Park City formation and the correlation of these members with the Phosphoria formation of Idaho and Wyoming have long been recognized. The lower member of the Park City formation at the type locality, however, has been assigned to the Pennsylvanian largely on the basis of fossils from limestone beds farther north that have been considered equivalent to the lower member of the Park City.[43] J. Stewart Williams[44] has recently assigned the lower member of the Park City to the Permian on the basis of inconclusive faunal and physical evidence. Fossils from the rocks in Faucett Canyon here included in the lower member of the Park City are of Permian age according to J. Steele Williams, who also considers collections from the lower member on the Duchesne River[45] to resemble fossils from the local Permian facies more than those from the local Pennsylvanian facies. The established Permian age of the limestone immediately underlying the middle phosphatic shale member near Midway strongly suggests Permian age for limestone of the lower member of the Park City at the near-by type locality and challenges the correlations of part or all the beds farther north that have been correlated with the lower member of the Park City.

Summary of Stratigraphic Relations

The stratigraphic relations presented in detail by systemic units in Figures 3–7 are combined in Figure 8 to present a comparison of the entire sections across the zone of thrust faulting. The sections are plotted to scale, and, by using the thicker western section as a standard, the thinner eastern sections are spread apart at the major unconformities in order to indicate the parts of the thicker section that are not represented. The diagram may be considered as a crude time chart with the thick western section used as a standard. Obviously the use of thicknesses of lithologic units without consideration of possible differences in rates of sedimentation and also the lack of fossils, or absence of adequate paleontologic studies, restricts the significance of the diagram to a generalized presentation of the writers' current concept of the stratigraphic relationships.

The Cambrian rocks are mainly limestone and dolomite with a thick sand-

[43] G. H. Girty in G. R. Mansfield, "Geography, Geology and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 78–79.

[44] J. Stewart Williams, "Carboniferous Formations of the Uinta and Northern Wasatch Mountains, Utah," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 618–19.

[45] J. Steele Williams in J. W. Huddle and F. T. McCann, "Geologic Map of Duchesne River Area, Wasatch and Duchesne Counties, Utah," *U. S. Geol. Survey Prelim. Map 75* (1947), Oil and Gas Inves. Ser.

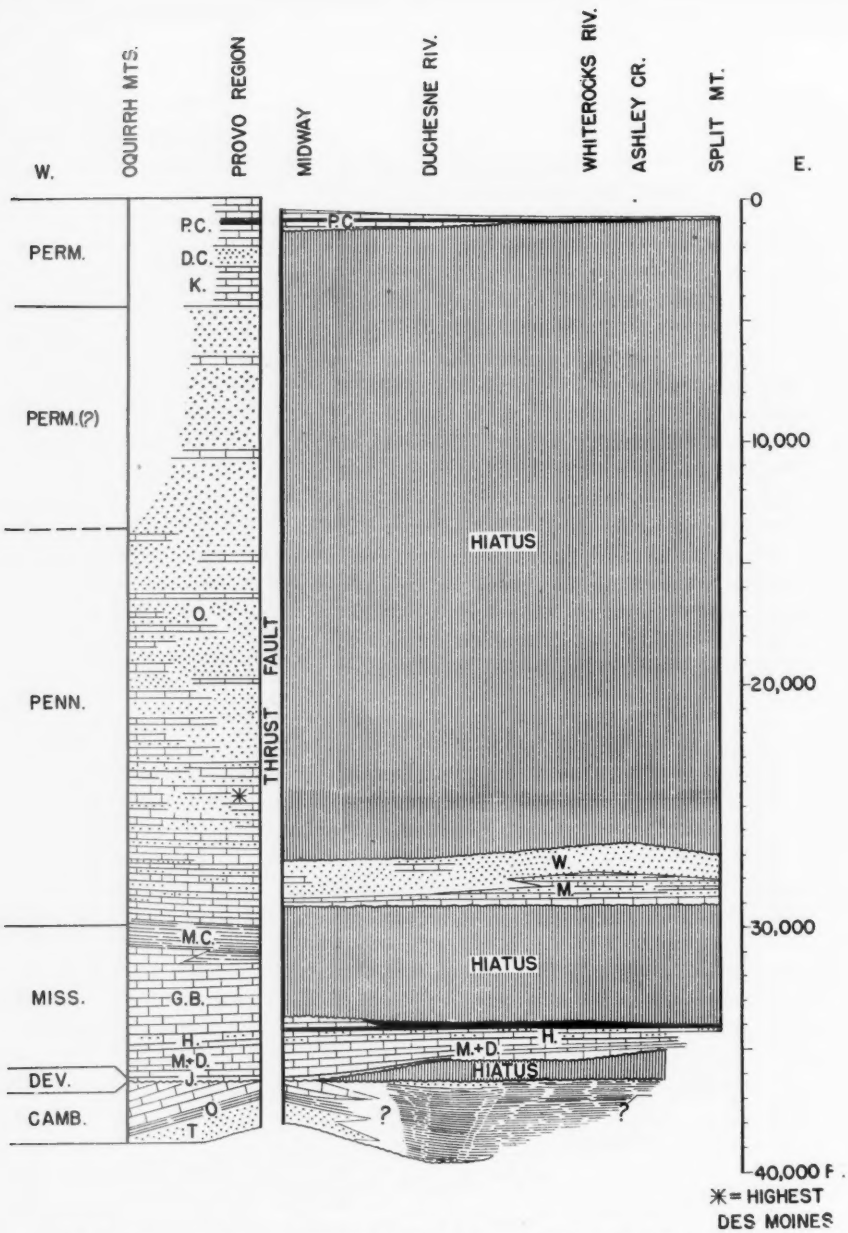

FIG. 8.—Composite diagram comparing stratigraphic sections along south flank of Uinta Mountains with section in southern Wasatch and Oquirrh mountains. P. C., Park City formation; D. C., Diamond Creek sandstone; K., Kirkman limestone; O., Oquirrh formation; W., Weber formation; M., Morgan formation; M. C., Manning Canyon shale; G. B., Great Blue limestone; H., Humbug formation; M.D., Madison limestone and Deseret limestone; J., Jefferson(?) dolomite; O., Ophir formation; T., Tintic quartzite.

stone unit in the western part of the area contrasted with thick shale and subordinate sandstone beds at eastern localities. Available fossils are inadequate to correlate between the two parts of the area but approximately equal parts of the Cambrian may be represented by the thicker parts of the section on the two sides of the thrust fault. Post-Cambrian erosion bevelled the rocks of Upper Cambrian age in the Oquirrh Mountains, and possibly on the Duchesne River, to those of low Middle Cambrian age locally in the Wasatch Mountains. The Cambrian rocks are overlain by the Jefferson(?) dolomite of Devonian age in the Wasatch Mountains, and by the Madison limestone of lower Mississippian age in the Uinta Mountains. The unconformity at the top of the Cambrian rocks thus represents all of Ordovician and Silurian time and part of the Devonian in the western part of the area and a somewhat longer period including the remainder of Devonian time along the south flank of the Uinta Mountains. In addition, an unknown amount of the lower Mississippian Madison limestone may be unrepresented toward the east as a result of overlap on the erosion surface.

Through the greater part of early lower Mississippian and the part of late upper Mississippian time, represented by the Madison, Deseret, and Humbug formations, comparable conditions prevailed across the area. The post-Humbug part of the upper Mississippian is represented, however, by several thousand feet of limestone and shale of the Great Blue limestone and the lower part of the Manning Canyon shale in the Wasatch Mountains, in contrast to a few hundred feet or less of limestone and dark shale north of the thrust fault in the Wasatch Mountains and along the Uinta Mountains. The precise correlation of the thin shale and limestone unit across the thrust fault has not been established, but its correlation with the base of the Great Blue limestone is consistent with known facts of lithology, stratigraphic position, and age. The writers provisionally accept that correlation, recognizing, however, that further paleontologic studies may indicate a somewhat later assignment in the Mississippian. Deposition in the Wasatch Mountains area south of the thrust fault appears to have been essentially continuous through the upper part of the Mississippian into the Pennsylvanian through Great Blue and Manning Canyon time, but if sediments equivalent to the greater part of these formations were deposited on the other side of the thrust fault in the Wasatch Mountains and along the Uinta Mountains, they were later removed by pre-Pennsylvanian erosion or perhaps during a period of erosion in upper Mississippian time. The Morgan formation of Pennsylvanian age rests on rocks considered by the writers to be equivalent to the basal part of the Great Blue limestone.

The oldest Pennsylvanian rocks in the Wasatch Mountains near Provo are included in the upper part of the Manning Canyon shale which is succeeded upward by a thick basal limestone unit of the Oquirrh formation. The basal limestone contains abundant fossils of early Pennsylvanian age. Later Pennsylvanian and early Permian time is represented by the enormously thick sequence of dominantly clastic sediments of the Oquirrh formation and the overlying Kirk-

man limestone and Diamond Creek sandstone. Sedimentation was probably nearly continuous in the southern Wasatch Mountains from earliest Pennsylvanian to Kaibab and later Permian time. The corresponding sequence on the other side of the thrust fault includes only the relatively thin Morgan and Weber formations. The lower limestone member of the Morgan is probably the equivalent of part of the basal limestone of the Oquirrh formation. The upper member of the Morgan contains a fusulinid fauna of Des Moines age, and the megafossils of the Weber of western localities are also Des Moines in age. The upper member of the Morgan formation and the western Weber thus appear to be correlative with a part of the lower few thousand feet of the clastic sediments of the Oquirrh formation. The age of the Weber sandstone in the eastern part of the Uinta Mountains is indeterminate in the absence of fossils. Correlation of the Weber sandstone with the Permian Diamond Creek sandstone of the southern Wasatch Mountains, which is lithologically comparable and also immediately underlies the Park City formation, has been suggested by several geologists. In the opinion of the writers, the evidence favors correlation of the Weber sandstone with the Weber quartzite of the Wasatch Mountains and early Pennsylvanian age for the sandstone.

Assignment of the Weber sandstone to the early Pennsylvanian means that a large part of Pennsylvanian and early Permian time is unrepresented north and east of the thrust fault in the Wasatch and Uinta mountains at an unconformity between the Weber sandstone and the Park City formation. The interval is represented farther south in the Wasatch Mountains by the upper part of the Oquirrh formation of Missouri, Virgil, and Wolfcamp age and by the overlying Permian sediments up to and including the lower member of the Park City formation equivalent in age to the Kaibab limestones. The eastward disappearance of the lower member of the Park City along the Uinta Mountains indicates a somewhat greater interval at the unconformity in the eastern part of the range extending to the base of the middle phosphatic shale member of the Park City formation, which is equivalent in age to the Phosphoria (post-Kaibab). The persistence of the Weber sandstone with fairly uniform thickness along the Uinta Mountains seems to indicate little erosion at the unconformity. The gradual eastward thinning of the lower limestone of the Park City formation, and, beyond its eastern limit, the persistence of the relatively thin middle phosphatic shale member of the Park City above the unconformity clearly indicates very low relief on the unconformity.

The middle phosphatic black shale member of the Park City formation is considered to provide an excellent stratigraphic tie across the thrust fault. Both the lower and upper limestone members of the Park City formation are less prominently developed in the thin section than in the thick section. The lower member wedges out eastward, and its disappearance is ascribed to overlap at the unconformity at its base.

Geologic History

The Paleozoic history of the region includes periods of repeated submergence of the land with marine deposition and intervening periods of erosion but with no intense deformation until post-Paleozoic time.

Rocks of Lower, Middle, and Upper Cambrian age were deposited in part of the area now occupied by the Uinta Basin and probably extended entirely across it. Rocks also of Ordovician and possibly Silurian age may have extended across the Uinta Basin, but if deposited they have been removed by erosion. Erosion during part or all of the period from the end of the Cambrian to Middle or late Devonian time removed all post-Cambrian sediments that may have been deposited and bevelled the Cambrian strata. A surface of low relief was formed on which the relatively thin but widespread Jefferson(?) dolomite of Devonian age was deposited.

Late Devonian and earliest Mississippian time was a period of emergence and erosion during which the Jefferson(?) dolomite may have been removed from the part of the region occupied by the eastern Uinta Mountains. Lime deposition was renewed in lower Mississippian time and continued into upper Mississippian time throughout the area with the apparently uninterrupted accumulation of the sediments in the Madison, Deseret, and Humbug formations. Sedimentation continued in the western part of the region through the remainder of the Mississippian and into Pennsylvanian time with the accumulation of the Great Blue limestone and the Manning Canyon shale. The eastern part of the region on the other hand became a positive area in late Mississippian time, received little sediment, and was subjected to erosion during most of the interval.

Similar conditions prevailed during the Pennsylvanian and early Permian, with a subsiding area in the west receiving dominantly clastic sediments more or less continuously in contrast to the eastern part of the area which has no record of sedimentation after Des Moines time in the Pennsylvanian or in the early Permian. The elevation of the eastern part of the area appears to reflect a northern extension of the Uncompahgre-San Luis highland of eastern Utah and southwestern Colorado that was elevated in the late Pennsylvanian or early Permian.

The incursion of the Park City sea in the later Permian extended across the Uinta Basin and was followed in at least part of the area by uplift and erosion of the surface upon which the redbeds of the Triassic were deposited.

The major structural features of the region are the result of at least two important periods of deformation. Folding and faulting occurred in a succession of movements in Upper Cretaceous time and the thrust faulting occurred at that time. Later folding, normal faulting, and reverse faulting involve rocks of late Upper Cretaceous and Tertiary age possibly as young as Oligocene. Some deformation probably continued throughout the Tertiary, and there is abundant evidence of very recent movement along the front of the Wasatch Mountains.

Extent of Thrust Fault and Possible Effect on Subsurface Conditions beneath Wasatch Mountains and Eastern Part of Great Basin

The full extent of the zone of thrust faulting near Heber Valley is not known, but inferences based on available information suggest that the thrust faulting may be an important factor in interpreting subsurface conditions beneath a large area including the southern Wasatch Mountains and the eastern part of the adjoining Great Basin.

The main thrust fault has been traced for about 20 miles from east of Heber to the canyon of American Fork. It trends east and near Heber dips 18°–20° south. Its extension at either end is not certain. Toward the west the fault plane has probably been involved in the deformation associated with the intrusion of the Cottonwood stock. Furthermore, the fact that the thrust faulting preceded the block faulting along the front of the Wasatch Mountains is clearly shown near Provo by displacements of the plane of a large subsidiary thrust fault by normal faults. There can be little doubt, therefore, that the main thrust fault is offset several thousand feet where it intersects the zone of normal faulting on the west side of the Wasatch Mountains. The occurrence of the thick section of late Paleozoic rocks in the Oquirrh Mountains and of the thin section in the Cottonwood region of the Wasatch Mountains indicates that the trace of the thrust fault follows the intervening valley where it is concealed by the sediments of Lake Bonneville. Thrust faults farther north in the Promontory Range, near Willard, and elsewhere in north-central Utah may represent a continuation of the same zone of thrust faulting, but the continuity can not now be demonstrated. Southeast from Heber the regional distribution of outcrops appears to limit the position of the zone of thrust faulting to the vicinity of the headwaters of the Strawberry River where the strata are known to be highly disturbed. Farther south it is apparently concealed for many miles beneath Tertiary sediments but may swing southwestward in conformity with the general structural trend of the Wasatch Mountains and may connect with thrust faults observed by Eardley[46] at the extreme southern end of the Wasatch Mountains. The thrust fault is assumed to separate the section of Paleozoic rocks at the southern end of the Wasatch Mountains which are characteristic of the thick section in the overthrust plate, from the next outcrops to the east in the San Rafael Swell and along the Colorado River which are more closely related to the sections typical of the Uinta Mountains.

No evidence is available to indicate the total horizontal movement in the zone of thrust faulting, but, on the basis of the magnitude of the differences in the two sections on opposite sides of the zone, it seems safe to infer that the movement was great, and resulted in the juxtaposition of facies originally deposited many

[46] A. J. Eardley, "Structure and Physiography of the Southern Wasatch Mountains, Utah," *Michigan Acad. Sci., Arts, Letters*, Vol. 19 (1934), pp. 377–400.

miles apart. Horizontal displacement of this inferred magnitude probably could have been accomplished only on a fault plane or series of fault planes with a low dip angle. Hence the sole of the thrust fault zone may be at relatively shallow depths below the southern Wasatch Mountains and possibly for many miles westward into the Great Basin, although the block faulting in the Basin would be expected to cause repeated offsetting of the thrust plate. As a result of such normal faulting and subsequent erosion, the thrust plane may be exposed in some of the mountain ranges west of the Wasatch Mountains, and further geologic work in the region may provide additional information on the age, distribution, and structure of the rocks in the overridden block, on the depth to the thrust plane, and on the amount of horizontal movement along the fault.

The geologic conditions observable in the surface rocks in the southern Wasatch Mountains and the adjoining part of the Great Basin probably offer little clue to the subsurface structural or stratigraphic conditions beneath the zone of thrust faults. In addition to buried structural conditions that may be favorable for the accumulation of oil, the transition from a thick section to a thin section of dominantly marine rocks occurring in the overridden block may provide potential stratigraphic traps that may not be beyond drilling depth. Other resources may also be present in mineralized areas at depth.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1198-1205, 1 FIG.

TECTONICS OF NORTH-CENTRAL STATES[1]

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ABSTRACT

The large Interior Coal basin is divided into three parts: the Indiana basin, the Illinois basin, and the small Kentucky basin. In the Indiana basin, both northeast and northwest trends are important. North- and northeast-striking folds produce most of the oil in the Illinois basin, although several marked northwest-striking folds and faults are productive, particularly on the LaSalle anticline—a very important feature. Northwest-striking folds and faults predominate in the Michigan basin.

In Kentucky, north- and east-trending folds and faults are the important features governing oil production. In Missouri, northwest- and north-trending folds govern the gas and oil production. In Iowa, as yet non-productive of gas or oil, northwest folding predominates, although the Redfield anticline which strikes northeast is a marked feature.

All the prominent uplifts, anticlines, domes, and faults in this area were largely in their present forms not later than the end of the Appalachian revolution—late Permian.

Minor folding which largely controls the gas and oil accumulations between and around the main uplifts has been influenced by stresses developed by the huge uplifts, and by stresses set up in the great basins. Most of the folding tends to follow earlier movements.

No comprehensive analysis of the tectonics of the area can be made until the detailed historical geology has been determined. It is essential to know the earlier local deformations; the old shore lines; which formations are competent and which are incompetent; and to have a definite idea of the relative stresses developed by the different uplifts. The stresses from Laurentia, Appalachia, Llanoria, and Cascadia have generally been taken for granted as causing the folds and faults, but local stresses have undoubtedly been developed by the Ozark, Sioux, Wisconsin, and the Ontario uplifts, and by action in the basins between them.

The Shawneetown-Rough Creek fault mosaic is an exceptional feature. Hicks dome and the Wells Creek disturbance, both probably crypto-volcanoes, are probably related to the volcanic action which was earlier than the first faulting. The important mineralization of the faulted area came after the first faulting, and prior to the second faulting. Earthquakes within historical time are evidence of continued slipping along some of the faults in the Mississippi embayment.

INTRODUCTION

In preparing this discussion, the writer has drawn from many sources. The tectonic map is based primarily on the *Tectonic Map of the United States*[3] with a few minor additions and with many deletions of detail. Only the prominent features are shown.

It should be clearly understood that the contours on the Tectonic Map are based on different horizons and have not yet been tied to one key horizon, which is essential to a proper interpretation of the true relationships. For example, the top of the Ozark uplift is outlined mainly by contours on the top of the Mississippian beds on the north, and on top of the Pennsylvanian beds on the west flank of the uplift. In other places, contouring follows similar practices. Final contouring must, however, await the result of subsurface studies of paleogeology that are yet merely in their infancy. However, some pertinent features

[1] Read before the Association at Eastern Interior regional meeting, St. Louis, January 14, 1948. Manuscript received, January 5, 1949.

[2] Consulting geologist. The material presented in this paper is brief and introductory, and is designed to promote discussion of the many problems. Present statements are tentative only, and the satisfactory answers can not be supplied until far more detailed information is available.

[3] Committee on Tectonics, Division of Geology and Geography, National Research Council. Published by Amer. Assoc. Petrol. Geol. (1944).

can be discussed which cast some light on the problems encountered, but any conclusions must at this time be considered tentative.

OUTSTANDING TECTONIC FEATURES

The outstanding tectonic features of the north-central United States are the three large basins, namely, the Forest City, the Michigan, and the Eastern Interior Coal basins bordered on the northeast, north, and northwest by the Ontario, Wisconsin, and Sioux uplifts, respectively; by the Nemaha ridge on the west, by the Ozarks on the southwest and south, and by the Cincinnati arch on the southeast and the east.

At one time, the Forest City basin, Eastern Interior Coal basin, and Michigan basin were all part of one great basin which was separated from the Appalachian basin by the old Cincinnati-Nashville landmass, but later they were cut into three smaller basins. The Kankakee arch separates the Michigan basin from the Interior Coal basin by the Mississippi arch and is bordered on the east by the Cincinnati-Nashville arch (Fig. 1).

The relative depths of the three basins are Forest City, 8,000 feet, and the Michigan and the Eastern Interior Coal basins, 13,000–14,000 feet each at the deepest depressions.

The Eastern Interior Coal basin is divided into two lobes of unequal size by the LaSalle anticline and by the Cumberland uplift. The eastern lobe is smaller than the western. On the south, the eastern lobe extends into Kentucky where it is crossed by the Rough Creek fault system. The eastern lobe, comprising the Illinois basin, extends south where its tip lies between the Cumberland and the Ozark uplifts.

The Cincinnati-Nashville arch forms a boundary between the deep Appalachian geosyncline and the Michigan and the Eastern Interior Coal basins. The Appalachian basin occupies a deep geosyncline in which 35,000–40,000 feet of sediments were deposited. It is bounded on the east and southeast by the Appalachian uplift, which is complicated by thrust folds and fault blocks evidencing great stresses in the past.

The Appalachian basin lies on the southeast margin of the continental core which is well exposed in the Canadian shield, while the three shallower basins (the Forest City basin, Eastern Interior Coal basin, and the Michigan basin) occur in minor depressions on the south flank of the Canadian shield.

MOST FEATURES PROMINENT AT END OF APPALACHIAN REVOLUTION

Near the end of the Permian period, the Appalachian revolution occurred. It was then that Laurentia, Appalachia, Llanoria, or Columbia pressed in on the north-central area. The islands comprising the Ontario, Wisconsin, Sioux, and Ozarks uplifts were highly elevated. At the same time, the basins between the various uplifts were depressed and also compressed in varying degrees.

The area has undergone at least two periods of minor subsidence and two

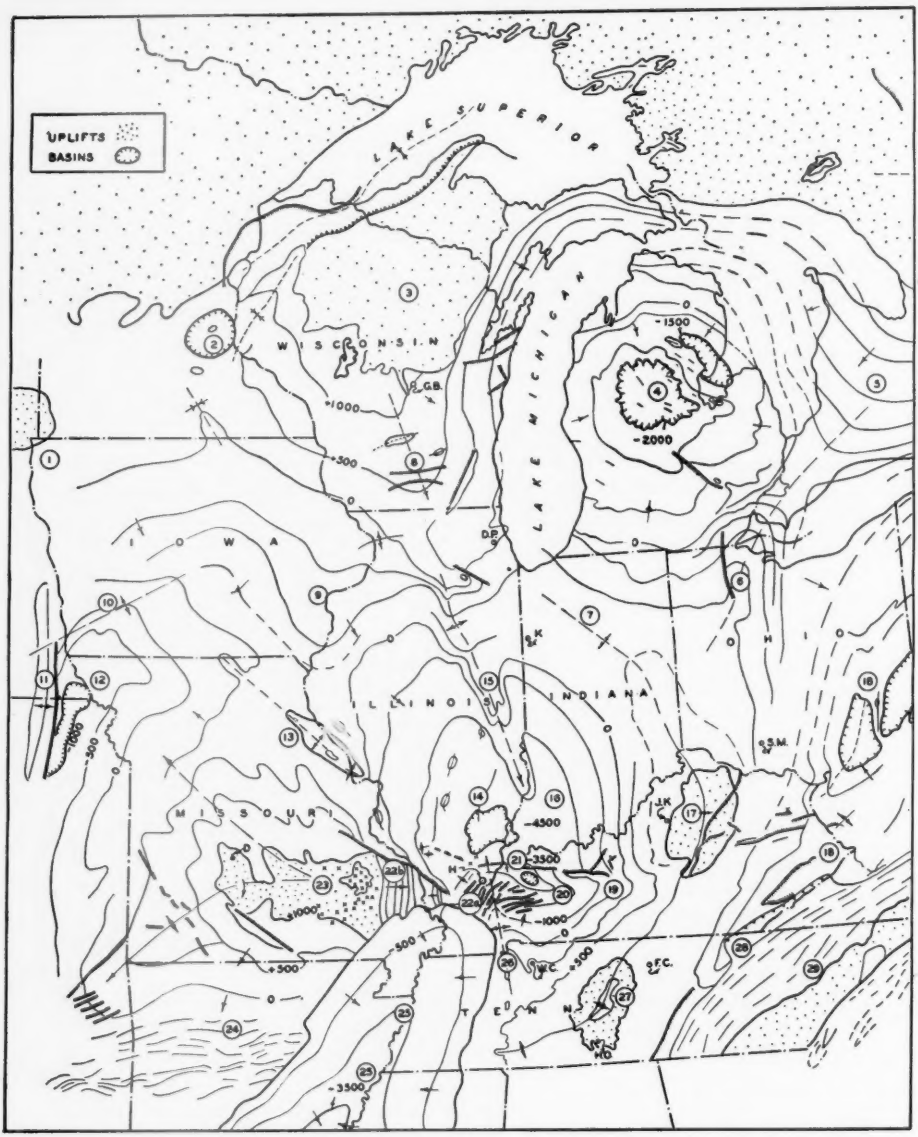

FIG. 1.—Tectonic map of north-central United States. (After U. S. Geol. Survey, Amer. Assoc. Petrol. Geol., and others, with a few additions.)

1. Sioux uplift
2. Minneapolis basin
3. Wisconsin uplift
4. Michigan basin
5. Ontario uplift
6. Findlay arch
7. Kankakee arch
8. Wisconsin arch
9. Mississippi arch
10. Redfield anticline
11. Nemaha ridge
12. Forest City basin
13. Lincoln fold
14. Illinois basin
15. LaSalle anticline
16. Indiana basin
17. Cincinnati arch
18. Appalachian geosyncline
19. East Kentucky fault system
20. Kentucky basin
21. Shawneetown-Rough Creek fault system
22a. Southern Illinois-West Kentucky fault system
22b. Ste. Genevieve fault
23. Ozark uplift
24. Arkansas basin
25. Mississippi embayment
26. Cumberland arch
27. Nashville dome
28. Pine Mountain overthrust
29. Appalachian uplift

Disturbances: G. B.—Glover Bluff; D. P.—Des Plaines; K.—Kentland; J. K.—Jeptha Knob; S. M.—Serpent Mound; F. C.—Flynn Creek; W. C.—Wells Creek; H.—Hicks Dome; D.—Decaturville.

of minor uplift since the Appalachian revolution. At present, there is no way to deduce what happened during the Triassic and Jurassic periods, except to state that apparently the area was largely a landmass during those epochs.

During Cretaceous time, some beds were deposited over part of the area as far north as Wisconsin. Uplift took place at the end of Cretaceous time when the Laramide revolution occurred.

Also, during the Laramide revolution, the Appalachian geosyncline was elevated into a broad arch nearly 2,000 feet high in the Appalachian area, but is assumed to have caused only 200–300 feet of elevation in the Mississippi Valley section. What effect such a movement had in intensifying the folding and faulting can not be readily ascertained.

At the end of Cretaceous, there was an interval of erosion followed by subsidence over part of the area when some Tertiary beds were deposited in the Mississippi embayment. Then the area was finally uplifted during the Coastal revolution at the end of the Tertiary period when the Killarney Mountains of Wisconsin, the present Ozarks, and other prominent tectonic features were accentuated. All structural features in the basin areas were affected, and original dips either intensified or weakened.

There is a question how far late uplift of the Ozarks extended before it encountered the effects of the Wisconsin uplift. To amplify, the west dips on the flanks of the folds in Illinois were elevated, while the east were further depressed for the folds near the Ozarks. This is clearly evident along the Duquoin anticline where the west dips are low but the east dips are more rapid. The Wisconsin movement, however, tilted the northern part of Illinois which weakened north plunges and accentuated the south plunges. In Michigan, elevation of the Ontario uplift accentuated the southwest dips, while weakening the northeast dips.

That some movement still persists is evidenced by the earthquakes which occur from time to time in the Mississippi Valley. The last great earthquake occurred in 1813 in the New Madrid area of Missouri. Also, in recent years, docks 60–70 years old in Upper Michigan which once extended out in the water are now on dry land, yet the level of the lakes is higher than before. This slow rising toward the northeast may be the result of upward movement in the Canadian shield itself, or due to the adjustments caused by the withdrawal of the ice which covered this area.

IGNEOUS ACTIVITY MINOR

The period of the most intense folding and faulting was not accompanied by much igneous activity within the basins, although the few crypto-volcanoes, dikes, and sills in southern Illinois and in western Kentucky are evidence of such activity. That the major folding and faulting was pre-Cretaceous seems clear, since the folding and the faulting do not cut through the Cretaceous beds of southern Illinois, west Kentucky, and Tennessee. The faults mapped in the Paleozoic beds pass under the later beds. Some late Tertiary faulting is evidenced at Thebes, Missouri, but it is minor in the extent.

EARLY TECTONIC MOVEMENTS

Nearly all the main structural features described were uplifts and basins during earlier geological periods. Deposits in all the basins include beds of earlier periods from Cambrian to, and including, the Pennsylvanian period. Some epochs may be absent, but deposits of the major periods are represented.

While the age of the latest movements can be set, and it is such movements that have resulted in the present tectonic pattern, movements are known to have occurred during Cambrian, Ordovician, Devonian, Silurian, and the Mississippian periods, and they must have influenced the later movements which in many instances closely follow the lines of weakness developed in earlier times. In many folds, the dips on the Pennsylvanian beds are low, but the dips at depth are intensified. Dips in such lower beds may be from two to three times as intense as in the upper beds with notable thinning of some formations on the crests of the folds, that is, marked unconformity.

Pennsylvanian folding is normally gentle. Broad noses and low domes are mapped on the coal beds. In many places in the Eastern Interior Coal basin where oil fields have been found, the subsurface highs agree with the coal highs. The coal high may be broad and flat, but the subsurface fold is sharper. Noses mapped on coal beds may become well developed folds at depth. Many coal highs, such as Campbell Hill, Omaha, Dale, Dix-Louden, Bartelso, Hoffman, Sandoval, and others have become productive, but in other places, the coal structures do not reflect the folds in older beds.

ORIGIN OF STRUCTURAL FEATURES UNCERTAIN

In attempting to evaluate the origin of the structural features of the area, one immediately encounters many questions that are at present difficult to answer, since too little is known of the paleogeology and paleogeography. It will be many years before such data are assembled and are carefully studied. One can analyze and project forces and stresses with their resulting strains, and thus create pictures that seem to satisfy the conditions, but it is largely guessing. For example, the attitude of beds during the late Ordovician period has a distinct bearing on what happened in later periods. A great arch, nearly 100 miles west of the present position of the Cincinnati arch is postulated to have crossed western Indiana and to have extended into central Michigan at that time, but the effect of this arch on later movements is unknown.

PROBABLE CAUSES OF LOCAL FOLDS

One can easily visualize pushes from old landmasses like Appalachia and Llanoria which have caused the intense folds and overthrusts of the Appalachians and of the mountains in southern Arkansas. Some of these stresses resulted in folds and faults in Tennessee, in Kentucky, in Missouri, and in southern Illinois,

even spreading across the Ozarks. But such stresses were not the immediate causes of the uplifts of Ontario, of Wisconsia, of Siouxia, and of Ozarkia. Local blisters of igneous rock of great size, probably contemporaneous with the Appalachian revolution, elevated those areas, while the sinking of the basins accounted for such arched ridges as the Mississippi arch between the Forest City basin and the Eastern Interior Coal basin and the Kankakee arch between the Eastern Interior Coal basin and the Michigan basin. The uplifting stresses had lateral components which formed couples that resulted in the series of folds crossing the various basins. It is, however, difficult at this time to recognize specific particular foci as the cause of folding.

It should be noted that contiguous to the Wisconsin and to the Ozark uplifts, the folds in general swing around the peripheries. These are due to the local stresses caused by uplift. However, as the stresses spread far out laterally from the uplifts, they act as couples, or there may be resolutions of forces that result in changes in the directions of the folds and faults dependent on the relative intensities of the interacting stresses.

The northwest-trending folds and faults in the Michigan basin may be the result of compressive movement from the Ontario uplift at the northeast. The dying-out of the intensity of movement from northeast to southwest Michigan suggests such stresses.

Many of the surface folds in Indiana trend northeast, parallel with the Appalachian movement, while the north-trending folds must have a different origin related to the same interactions as those in Illinois.

In the Forest City basin, the folds trend northwest, northeast, and north, dependent on their position in the basin and their relation to the Ozark uplift and Sioux uplift. The northwest trend continues into the Illinois basin, paralleling the long northwest axis of the Ozark uplift. The northwest folds found on the Ozark uplift undoubtedly come from a push from the south-southwest, probably a continuation of the movements in Arkansas, perhaps prior to uplift in the Ozarks. When the Ozark and the Wisconsin uplifts occurred, the lateral stresses formed a couple which accentuated the intensity of the northwest folds in the basins. Siouxian and Ozarkian stresses also formed a couple which resulted in northeast-trending folds across Iowa and parts of northwest Missouri.

The north- and slightly northeast-trending folds in Illinois are probably due to the interaction of a southern stress from the Wisconsin uplift with pushes from the Ontario and the Ozark uplifts and even from the Cincinnati arch.

The directions of local folding are not easily resolved, since all earlier lines of folding at the end of the Mississippian, of the Devonian, of the Ordovician, and the Cambrian periods must have had a decided influence on the directions of later folding. Later folding may or may not coincide with earlier folding.

Physical characteristics of the beds, their competency and incompetency, stratigraphic changes where competent beds change to incompetent, may affect

the forces and change the directions and the intensities of the stresses. Strike folds, especially those nearest the uplifts, coincide with the change in strike of the beds and curve around the uplifts, or may be slightly *en échelon*.

SHAWNEETOWN-ROUGH CREEK FAULT ZONE

The complicated mass of folds and faults which occurs in southeastern Illinois and which crosses into Kentucky is a most exceptional feature. It has been well described by Stuart Weller, and Marvin Weller,[4] and by Charles Butts.[5] The faults are mainly block faults, forming horsts and grabens. The strikes of the principal faults range from northeast to east, but many faults cut across that line of strike to form blocks of different sizes, forming a mosaic with no set pattern. In places, some of the fault blocks are highly folded. Upthrusting of considerable magnitude must have occurred. Mineralization occurred along the primary faults but not along the secondary faults. Magmatic waters brought zinc, fluorite, lead, and some silver to fill the fault planes of the primary faults along which numerous mines have been developed.

Prior to the primary faulting, igneous action occurred in this belt, as numerous dikes of basic rock cut northwest across the belt. The dikes that filled the fractures did not, however, follow the fault planes.[6]

Most of the faults that the writer has seen have dips between 60° and 90° or hades between 30° and 20° from vertical. The vertical throws of the faults are as large as 3,500 feet. A set of later faults cuts the first set into a mosaic pattern. Some of the fault blocks are tilted as much as 1,500 feet.

HICKS DOME-WELLS CREEK DISTURBANCES

Hicks dome, part of this movement, is a high structural feature which rises 2,000 feet vertically, a feature comparable with, but larger than the Wells Creek disturbance of Tennessee, the latter a recognized crypto-volcano.

The similarity in the features of the Hicks dome and the Wells Creek disturbance is suggestive of similar origin. In each, the central doming, the outer anticlines and synclines, and the fault patterns suggest that Hicks dome is of the same type of structure as Wells Creek, although the Hicks dome disturbance covers three times the area of Wells Creek, or 200 compared with 60 square miles.

The intrusives of basic rocks, dikes, and sills in the areas contiguous to Hicks dome denote plutonic action, and suggest that Hicks dome is the expression of

[4] J. Marvin Weller (includes references to Stuart Weller), *Illinois Geol. Survey Rept. Inves. 71* (1940).

[5] Charles Butts, "Geology and Mineral Resources of the Equality-Shawneetown Area," *Illinois Geol. Survey Bull. 47* (1925).

[6] This feature was discussed personally with G. H. Cady of the Illinois Geological Survey who assured the writer that the dikes do not follow the faults, nor as yet has he found any dikes cut by the faults, although it is possible some may yet be found.

a welling magma that left it as a blister. Wells Creek in Tennessee is probably similar in origin.

LASALLE AND CUMBERLAND UPLIFTS

The LaSalle anticline and the Cumberland arch are also two features that do not follow the pattern of other folds. Whether or not they are related movements is open to question, but their strikes suggest a relationship, and the position of the Illinois basin between them is also suggestive of such a relationship Is there also a connection between those folds and the Shawneetown-Rough Creek fault system?

The arcuate faulting and folding in southern Illinois and in western Kentucky, swinging from northeast, to east, to southeast around the Hicks dome area, suggests strongly a push from the southeast, since the steeper beds of most of the folds are on the northwest, north, and northeast.

The writer suggests that this arcuate condition could be the result of a push along the axis of the Cumberland uplift. At the same time, there is a push from the northwest or the southeast along the line of the LaSalle anticline, thus forming a couple which results in a set of faults between the Cumberland uplift and the LaSalle anticline which would explain many of the northeast-trending faults in Illinois and in western Kentucky.

SUMMARY

1. Broad generalizations only now can be made regarding the actions of the stresses both those of linear type and those of shearing couples that have acted upon the north-central states to cause the tectonic features.

2. The resulting deformations that have been mapped are by no means simple to analyze due to lack of sufficient information.

3. Lines or belts of weakness in the older beds influence later deformations; in fact, they may furnish the lines or belts that later forces have affected.

4. Large unconformities, the relative positions of competent and of incompetent beds, the relative intensities of the forces, the directions of such forces and of resulting couples all affect the line or zone of strain.

5. Only a thorough knowledge of historical geology, paleogeology, and paleogeography can furnish the data necessary for sound interpretations of the local tectonics.

6. Such information is now only partial, and any interpretations of the tectonics are necessarily tentative.

7. The Shawneetown-Rough Creek fault zone is the most exceptional geologic feature in the north-central states and the most difficult to interpret.

8. Hicks dome is a probable blister due to the upward push of magmatic material beneath it. Wells Creek, a recognized crypto-volcano, is a similar feature, only smaller.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1206-1250, 3 PLS., 10 FIGS., 3 TABLES

UPPER JURASSIC OF NORTHEASTERN TEXAS[1]

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ABSTRACT

The entirely subsurface Upper Jurassic of northeastern Texas includes, in ascending order, the Eagle Mills, Smackover, Buckner, Bossier, and Schuler formations; the last two constitute the Cotton Valley group. The stratigraphy of the units in northeastern Texas is described.

Present evidence suggests that, in the East Texas basin, the Buckner formation passes downdip into the upper part of the Smackover formation.

The Bossier formation is thinner than in Louisiana and contains oölitic limestone beds that suggest deposition in a sea that was shallower than in northwestern Louisiana.

The Schuler formation in Texas, as in Arkansas and Louisiana, consists of two members, each of which occurs in a marine and a non-marine facies. The lower, or Shongaloo, member in Texas is similar lithologically to occurrences farther east, but its change of facies is farther updip than in Arkansas and Louisiana. The Dorcheat member is similar in general lithologic character to its occurrences in Arkansas and Louisiana but in Texas it almost entirely lacks zones of spherulitic siderite that are characteristically developed farther east. Zones of this material are reported to indicate intervals of prolonged weathering in the Coal Measures of England. Absence of the siderite in the Dorcheat of Texas suggests that deposition was more continuous.

Several species of Ostracoda from the Schuler formation are illustrated.

INTRODUCTION

The attempt is made to bring up to date the information provided by deep wells on the stratigraphy of the Upper Jurassic of northeastern Texas. Although the paper is based on information from 60 wells in East Texas, the area is large, the control sparse, and many of the relationships are incompletely known.

Figure 1 shows the generalized structure of the East Texas basin and adjoining areas, but does not illustrate local features, which may be seen on the structural map of Texas (Sellards and Hendricks, 1946). The data do not permit delineation of the large Preston anticline that trends northwest-southeast in Hunt County or of the Sherman syncline that flanks it on the southwest.

On the basis of present information, it seems plausible to recognize a grouping of the pre-Cretaceous subsurface units of Mesozoic age in the northern Gulf Coastal Plain as follows (in order of increasing age).

Upper Jurassic series
  Cotton Valley group
    Schuler formation
      2. Dorcheat member
      1. Shongaloo member

[1] Published by permission of the director of the United States Geological Survey. Manuscript received, December 8, 1948.

[2] Department of geology, University of Minnesota. Sets of well samples and much additional information were made available by W. B. Weeks and Joseph Purzer, Phillips Petroleum Company; by F. W. Rolshausen and T. J. Burnett with permission of Morgan J. Davis and E. A. Wendlandt, Humble Oil and Refining Company; by H. C. Matheny and W. D. McEachin, Sinclair-Prairie Oil Company; by C. I. Alexander and J. T. Rouse, Magnolia Petroleum Company; by E. B. Hutson, Carter Oil Company; by A. C. Wright, Shell Oil Company; by R. T. Hazzard, Gulf Oil Corporation; and by W. E. Wallace, Jr., Sohio Petroleum Company. Sincere appreciation is expressed to these individuals and their companies. Assistance in preparation of maps, charts, thin sections, and photomicrographs was provided by L. M. Perry, L. E. Monley, and R. F. Hadley. X-ray and chemical examinations of salt were made by Lynn Gardner. The work was supported by the United States Geological Survey, and by a grant-in-aid from the Graduate School, University of Minnesota.

Bossier formation
2. Offshore dark shale and impure limestone facies, at least partly younger than the following
1. Nearshore sandstone and shale facies
Unnamed group of strata
?Nearshore sandstone and red shale unit[1]
Buckner formation (probably equivalent to dense upper part of Smackover formation of deeper parts of basins)
2. Nearshore red and green shale, anhydrite, and nodular dolomite, with offshore oölitic facies in upper part
1. Anhydrite and dense dolomitic limestone member, locally containing rock salt
Smackover formation
3. Offshore dense limestone (probably equivalent to Buckner formation)
2. Nearshore thin, oölitic, partly dolomitic, porous limestone unit (Reynolds oölite)
1. Dense, partly dolomitic, partly sandy limestone and shale
Eagle Mills formation[2]
4. Nearshore, probably non-marine redbeds (Norphlet formation of Hazzard, Spooner, and Blanpied, 1945), in part interfingering with lower part of Smackover
3. Massive salt and anhydrite unit having abrupt termination updip
2. Nearshore, probably non-marine, redbeds with basal conglomerate in some places; in Monroe uplift this unit may pass southward into gray Morehouse shale of Imlay or may be entirely younger than it
1. Redbeds of uncertain age penetrated in wells in Ashley County, southeastern Arkansas, that exceed 4,500 feet in thickness; may represent Jurassic older than Oxfordian, or Triassic, or Permian

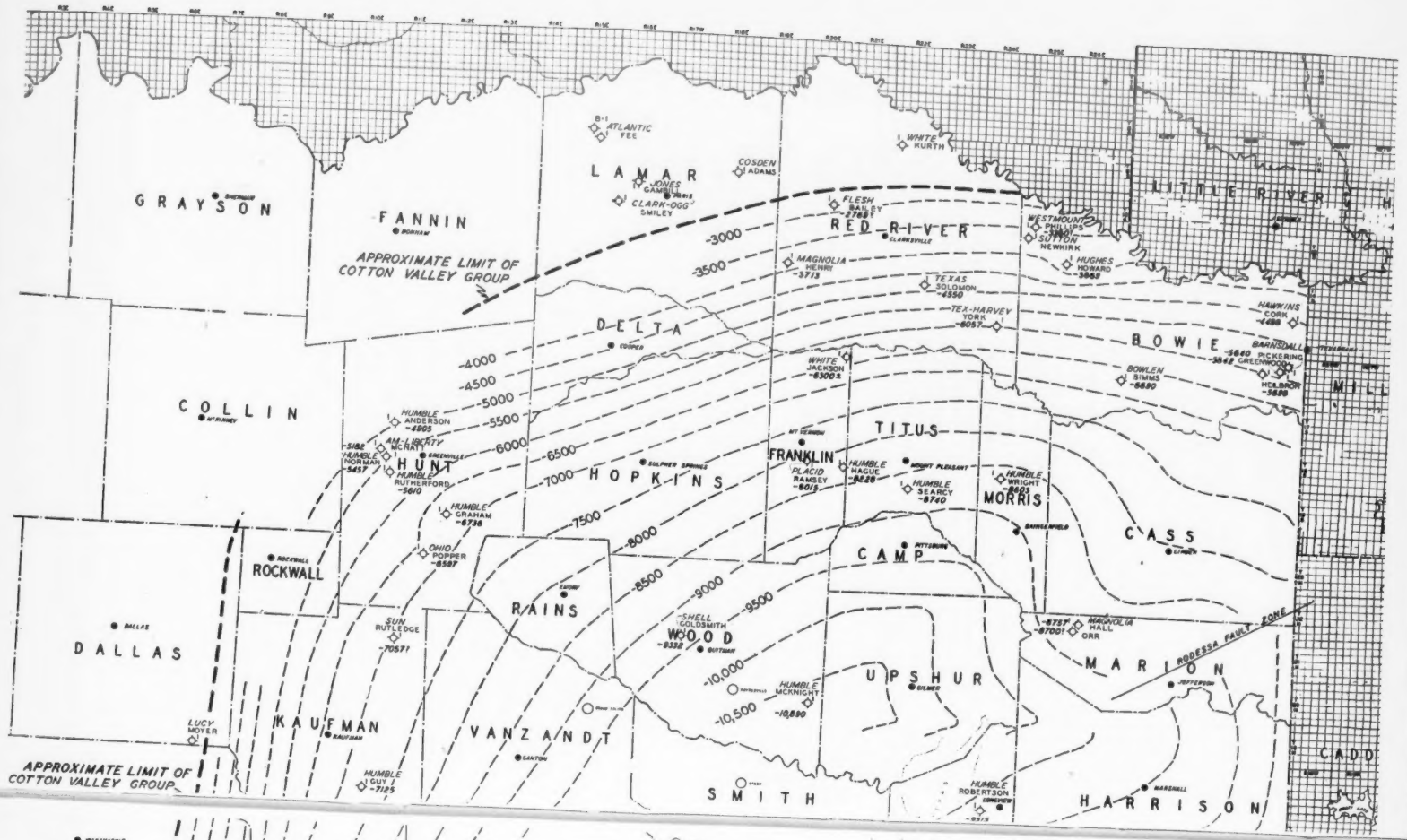
[1] Based on observations by R. M. Wilson in Haynesville field and other areas of Arkansas and Louisiana.
[2] Includes, in ascending order, Werner formation, Louann salt, and Norphlet formation of Hazzard, Spooner, and Blanpied (1945), who believe that the type Eagle Mills is older than their Werner formation.

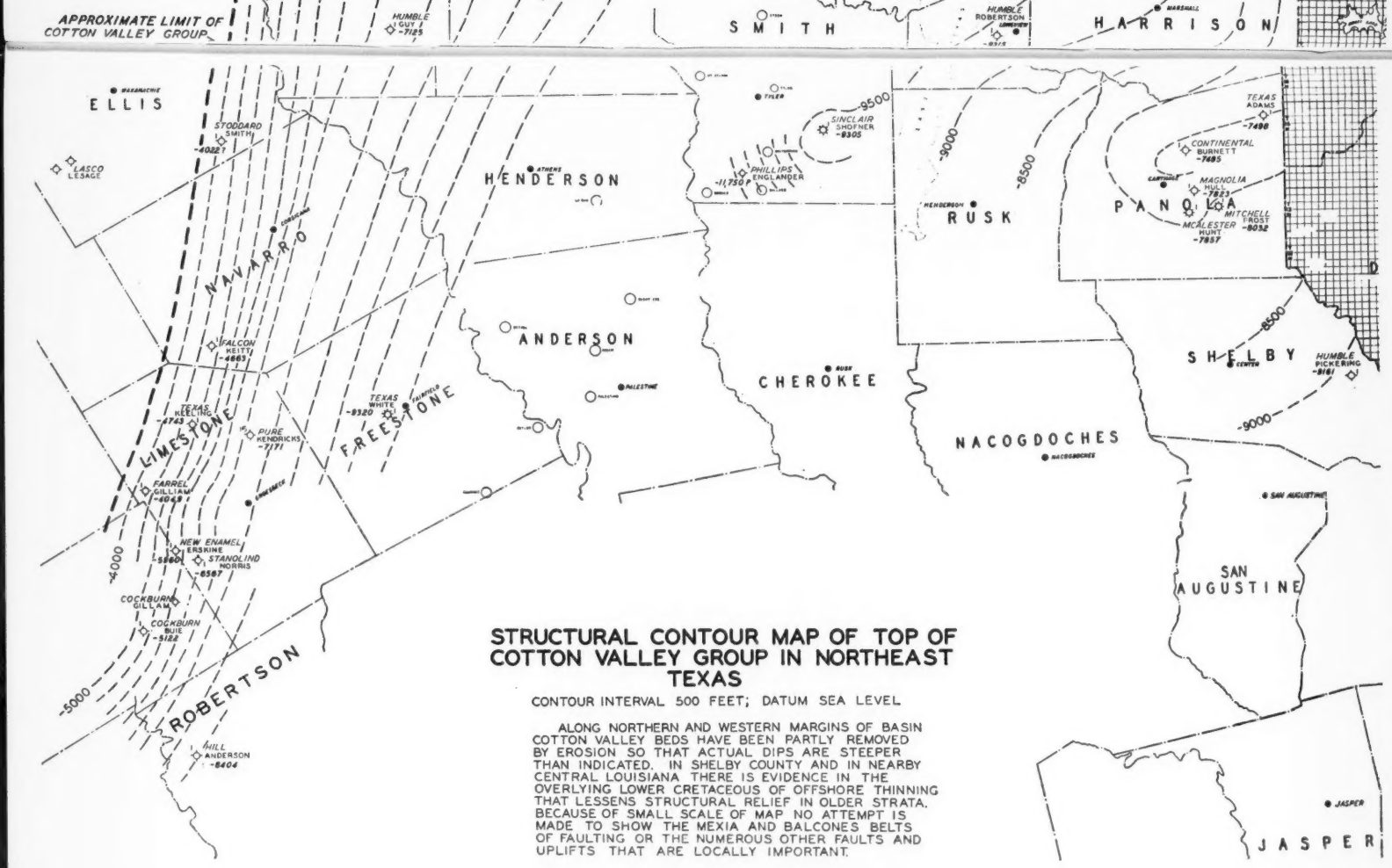
Soon after it was discovered by drilling, the salt now believed to be part of the Eagle Mills was tentatively placed in the Permian (Spooner, 1932), and more recently a similar designation was made (Hazzard, Spooner, and Blanpied, 1945). The writer is not now prepared to discuss this recent proposal, and in the present paper he follows Imlay (1943, pp. 1436–38) in assigning a Jurassic age to the Eagle Mills formation, including the salt. The salt mass shows no evidence of weathering. If the salt is Permian, an explanation of how it escaped extensive solution throughout Triassic and over half of Jurassic time should be provided.

EAGLE MILLS FORMATION

The stratigraphy of the Eagle Mills formation of redbeds, anhydrite, and salt, as disclosed by drilling to 1943, has been discussed by Imlay (1943, pp. 1407–1553). Many wells have penetrated the formation since that year, but as the new information in northeastern Texas serves mostly to supplement the previous data, a detailed discussion is not needed here. Table I summarizes the occurrence of the formation in northeastern Texas insofar as information was available to the writer to September, 1947. The stratigraphic sequences disclosed by most of the more recent wells are shown in Figures 3–7.

The Shell Oil Company's Goldsmith No. 12, Quitman field, Wood County, encountered anhydrite and rock salt at 11,170 feet. The salt is in contact with the lower part of the Schuler formation and probably represents a piercement dome rather than a fault contact with the Eagle Mills. If so, it represents one of the most northerly of the interior salt domes (Sellards and Hendricks, 1946). The Buckner formation contains rock salt in this part of Texas, and may provide


GRAYSON
FANNIN
LAMAR
RED RIVER
LITTLE RIVER
MILL
COLLIN
DELTA
BOWIE
HUNT
HOPKINS
FRANKLIN
TITUS
MORRIS
CASS
ROCKWALL
DALLAS
RAINS
WOOD
CAMP
MARION
KAUFMAN
VANZANDT
UPSHUR
SMITH
HARRISON
CADD
APPROXIMATE LIMIT OF COTTON VALLEY GROUP
APPROXIMATE LIMIT OF COTTON VALLEY GROUP
RODESSA FAULT ZONE
-3000
-3500
-4000
-4500
-5000
-5500
-6000
-6500
-7000
-7500
-8000
-8500
-9000
-9500
-10,000
-10,500
ATLANTIC FEE
JONES GAMBLE
CLARK-OGG SMILEY
COSDEN ADAMS
WHITE KURTH
FLESH BAILEY 2768
WESTMOUNTAIN PHILLIPS SUTTON NEWKIRK
MAGNOLIA HENRY -3713
HUGHES HOWARD -3869
TEXAS SOLOMON -4550
TEX-HARVEY YORK -6057
HAWKINS CORN -4498
BARNSDALL PICKERING CREEKWOOD -5640 -5662
BOWLEN SIMMS -5680
HELBROK -5690
WHITE JACKSON -6302
HUMBLE ANDERSON -4905
AM. AGRICULTY MCHANEY
HUMBLE NORMAN -5182 -5457
HUMBLE RUTHERFORD -5610
HUMBLE GRAHAM -6736
OHIO POPPER -6597
PLACID RAMSEY -6015
HUMBLE HAGUE -6226
HUMBLE SEARCY -6740
HUMBLE WRIGHT -6601
MAGNOLIA HALL ORR -6757 -6700
SUN RUTLEDGE -7057
SHELL GOLDSMITH -9332
HUMBLE MCKNIGHT -10,890
HUMBLE GUY -7125
HUMBLE ROBERTSON -9515
LUCY MOYER

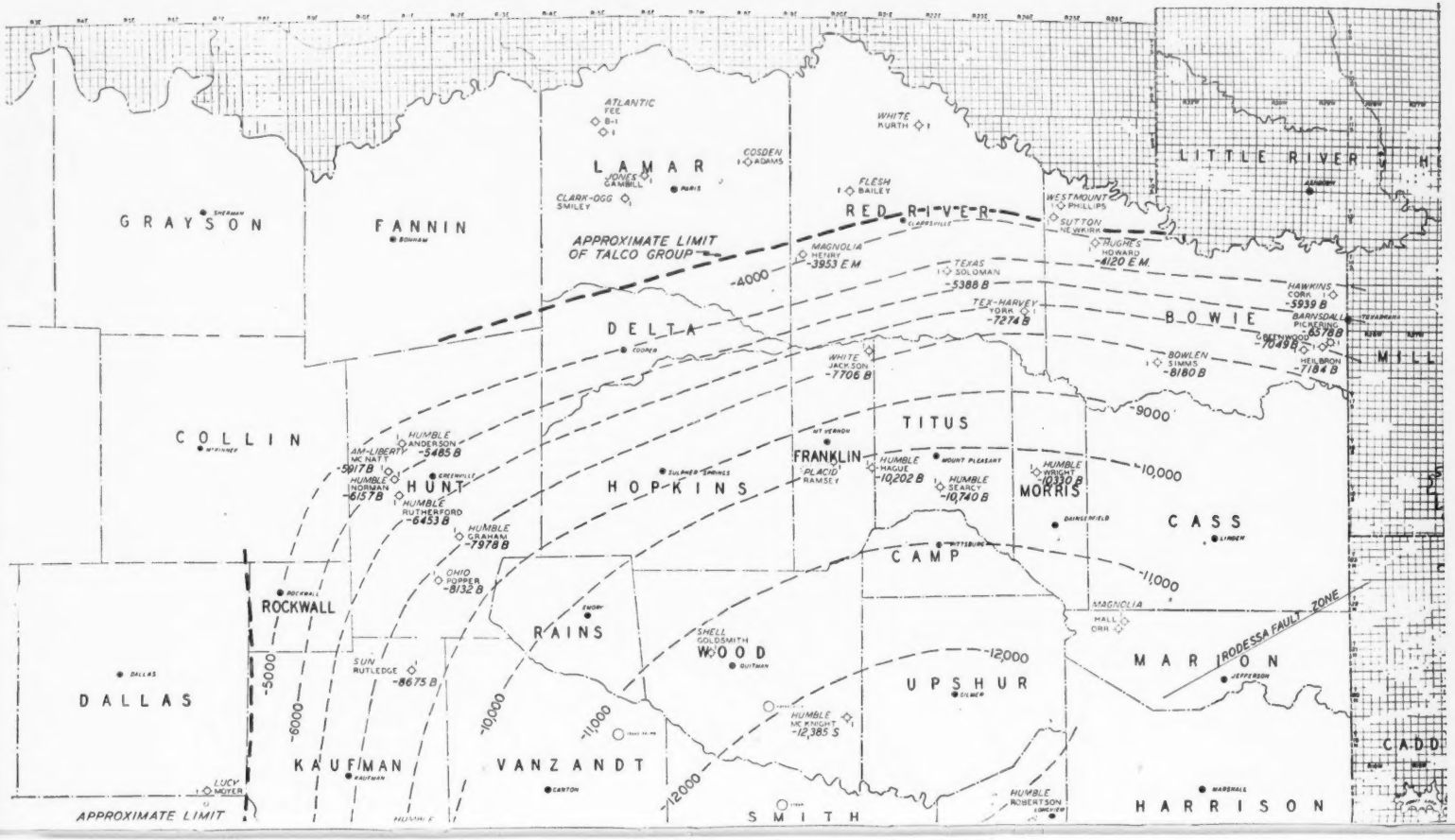


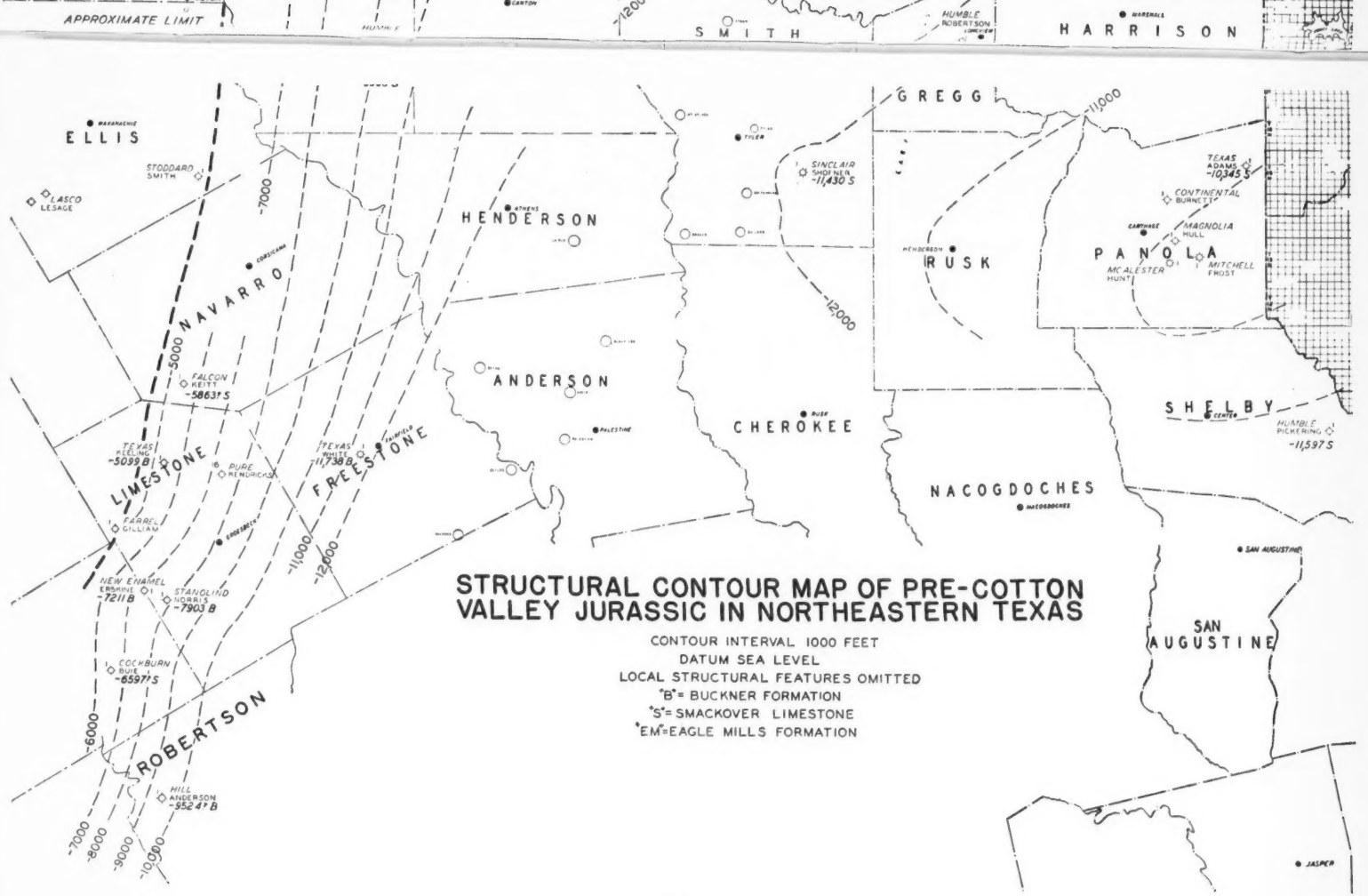
STRUCTURAL CONTOUR MAP OF TOP OF COTTON VALLEY GROUP IN NORTHEAST TEXAS

CONTOUR INTERVAL 500 FEET; DATUM SEA LEVEL

ALONG NORTHERN AND WESTERN MARGINS OF BASIN COTTON VALLEY BEDS HAVE BEEN PARTLY REMOVED BY EROSION SO THAT ACTUAL DIPS ARE STEEPER THAN INDICATED. IN SHELBY COUNTY AND IN NEARBY CENTRAL LOUISIANA THERE IS EVIDENCE IN THE OVERLYING LOWER CRETACEOUS OF OFFSHORE THINNING THAT LESSENS STRUCTURAL RELIEF IN OLDER STRATA. BECAUSE OF SMALL SCALE OF MAP NO ATTEMPT IS MADE TO SHOW THE MEXIA AND BALCONES BELTS OF FAULTING OR THE NUMEROUS OTHER FAULTS AND UPLIFTS THAT ARE LOCALLY IMPORTANT.

FIG. 1


GRAYSON
FANNIN
LAMAR
RED RIVER
LITTLE RIVER
MILL
DELTA
BOWIE
COLLIN
HUNT
HOPKINS
FRANKLIN
TITUS
MORRIS
CASS
CAMP
ROCKWALL
RAINS
WOOD
UPSHUR
MARION
DALLAS
KAUFMAN
VANZANDT
SMITH
HARRISON
CADD
APPROXIMATE LIMIT OF TALCO GROUP
APPROXIMATE LIMIT
MAGNOLIA
HALL ORR
-4000
-5000
-6000
-9000
-10,000
-11,000
-12,000
ATLANTIC FEE B-1
WHITE KURTH
COSDEN ADAMS
JONES CAMBELL
CLARK-OGG SMILEY
FLESH BAILEY
WESTMOUNT PHILLIPS
SUTTON NEWRIRK
HUGHES HOWARD -4120 E.M.
MAGNOLIA HENRY -3953 E.M.
TEXAS SOLOMAN -5388 B
TEX-HARVEY YORK -7274 B
HAWKINS CORK -5939 B
BARNSDALL PICKERING -6578 B
GLENWOOD -7049 B
HEILBRON -7184 B
BOWLEN SIMMS -8180 B
WHITE JACKSON -7706 B
HUMBLE ANDERSON -5485 B
AM-LIBERTY MC NATT -5917 B
HUMBLE NORMAN -6157 B
HUMBLE RUTHERFORD -6453 B
HUMBLE GRAHAM -7978 B
OHIO PIPPER -8132 B
HUMBLE HAGUE -10,202 B
HUMBLE SEARCY -10,740 B
HUMBLE WRIGHT -10330 B
SUN RUTLEDGE -8675 B
SHELL GOLDSMITH
HUMBLE MC KNIGHT -12,385 S
HUMBLE ROBERTSON
LUCY MOYER
RODESSA FAULT ZONE



STRUCTURAL CONTOUR MAP OF PRE-COTTON VALLEY JURASSIC IN NORTHEASTERN TEXAS

CONTOUR INTERVAL 1000 FEET
DATUM SEA LEVEL
LOCAL STRUCTURAL FEATURES OMITTED
"B" = BUCKNER FORMATION
"S" = SMACKOVER LIMESTONE
"EM" = EAGLE MILLS FORMATION

FIG. 2

the source of the anhydrite and salt, although in Kaufman County, the salt of the Buckner contains impurities not found in the Goldsmith well.

Along the northern and northwestern margins of the East Texas basin as far south as Ellis County, the rocks underlying the Eagle Mills consist of partly metamorphosed red and black phyllitic shales and quartzitic sandstones and are probably late Paleozoic in age. South of Ellis County, as shown in several wells, the Eagle Mills rests on ferruginous quartz-muscovite schist, that is evi-

TABLE I

OCCURRENCE OF EAGLE MILLS FORMATION IN NORTHEASTERN TEXAS

COMPANY	LEASE	COUNTY	LOCATION	TOP	BASE	TOP SALT	SALT THICKNESS	UNDERLYING ROCK	TOTAL DEPTH
BARNSDALL & SOHIO	PICKERING NO.1	BOWIE	R.E. SEVEY SURVEY FLOWER ACRES POOL	7379 (-7079)	——	——	——	——	7503
BARNSDALL & SOHIO	GREENWOOD NO.1	BOWIE	LEWIS T. KING SURVEY EYLAU POOL	7924 (-7616)	——	——	——	——	8188
HUGHES ET AL	HOWARD NO.1	BOWIE	J.M. DYER SURVEY 7 MI. N. OF DE KALB	4492 ? (-4120)	4545 ? (-4173)	——	——	RED & BLACK PHYLLITE	4590
TEX-HARVEY	YORK NO.1	RED RIVER	CHRISTIAN GROCE SURVEY 1-1/2 MI. SW OF LYDIA	8200 (-7879)	——	——	——	——	8232
MAGNOLIA PET CO	HENRY NO.1	RED RIVER	M.E.P. & P. RR #103 SURVEY 13-1/2 MI. WSW OF CLARKSVILLE	4425 ? (-3953)	4710 (-4238)	——	——	QUARTZITE CONGLOMERATE	4785
HUMBLE O&R CO	MC KNIGHT NO.1	WOOD	W.R. JAMES SURVEY HAWKINS POOL	14,290 (-13,930)	——	14,410 (-14,050)	259+	——	14,629
SINCLAIR-PRAIRIE	SHOFNER NO.1	SMITH	W. DICKERSON SURVEY CHAPEL HILL POOL	13,370 (-12,900)	——	?	?	——	13,577
WHITE ET AL	JACKSON NO.1	FRANKLIN	J.E. HOPKINS SURVEY 1 MI. W. OF TALCO	9030 (-8674)	——	9049 (-8693)	——	——	9084
AMERICAN-LIBERTY	MC NATT NO.1	HUNT	ENOS MURPHY SURVEY (A-647) 6 MI. WNW OF GREENVILLE	6690 (-6117)	6860 (-6287)	——	——	RED PHYLLITE	6895
HUMBLE O&R CO	NORMAN NO.1	HUNT	HIRAM THOMPSON SURVEY 4 MI. W. OF GREENVILLE	7028 (-6489)	7142 (-6583)	——	——	MOTTLED PHYLLITE	7157
HUMBLE O&R CO	RUTHERFORD NO.1	HUNT	SAMUEL LINDSEY SURVEY 4-1/2 MI. SW OF GREENVILLE	7362 (-6822)	7454 (-6914)	——	——	RED PHYLLITE	7482
HUMBLE O&R CO	GRAHAM NO.1	HUNT	WM. ELAM SURVEY 7 MI. SE OF GREENVILLE	9504 (-8972)	——	9514 (-8982)	——	——	9523
FALCON OIL CO	KEITT NO.1	NAVARRO	18 MI. SW. OF CORSICANA	6360 (-5893)	6446 (-5979)	——	——	SCHIST	6455
TEXAS CO	KEELING NO.1	LIMESTONE	WHITAKER SURVEY 13 MI. NW OF GROESBECK	5932 (-5404)	5000 (-5452)	——	——	SCHIST	6018
STANOLIND OIL CO	NORRIS NO.1	LIMESTONE	K. THRASHER SURVEY 11 MI. SW. OF GROESBECK	8995 (-8467)	——	8995 (-8467)	800	——	9951
TEXAS CO	WHITE NO.1	FREESTONE	WM. KING SURVEY 3-1/4 MI. W. OF FAIRFIELD	14,300 ± (-13,891)	——	——	——	——	14,334

dently related in age to the pre-Cambrian Llano series of gneisses and schists exposed in the Central Mineral region.

The age of the thin unit of partly metamorphosed shale found beneath the Smackover formation in the bottom of the Cockburn and Zephyr Oil Company's Buie No. 1, Falls County, is uncertain (Fig. 7).

SMACKOVER FORMATION

The stratigraphy of the Smackover formation in Arkansas and Louisiana has been described by Weeks (1938) and Imlay (1940, 1943). In northeastern Texas the limestones of the Smackover have been penetrated by drilling in Bowie, Panola, Shelby, Red River, Morris, Titus, Franklin, Wood, Hunt, Kaufman, Smith, Freestone, Limestone, and Robertson counties.

PANOLA AND SHELBY COUNTIES

The stratigraphy of the Smackover in The Texas Company's Adams No. C-1, Panola County, and the Humble Oil and Refining Company's Pickering No. 1, Shelby County, is shown in Figure 3. In the Adams well the upper part of the formation consists of argillaceous limestone and interbedded gray shale; the lower part is dense argillaceous limestone. The upper, more shaly, part is here interpreted as representing the offshore equivalent of the Buckner formation, but some of the geologists who are familiar with the area do not accept this interpretation. Drill cuttings were not available from the Humble's Pickering well and the correlation shown in Figure 3 is based on interpretation of the electrical log.

BOWIE COUNTY

In the Eylau field, east-central Bowie County, where the Smackover formation is petroliferous (Fig. 3), it consists of 16 feet of oölitic, sandy, dolomitic limestone at the top, and sandstone, reworked igneous material, together with intrusions of probably mafic igneous rocks in the lower part. In Bowlen's Simms No. 1, south-central Bowie County (Fig. 4), the Smackover shows no evidence of local igneous activity, but contains many dolomitic layers, and the upper 50 feet are oölitic. No Smackover is present in Hughes' Howard No. 1 (Figs. 2, 3) in northwestern Bowie County, but it is present in Hawkins' Cork No. 1 in the northeastern part of the county, 5 miles northwest of Texarkana (Fig. 2), and in The Texas Company's Solomon No. 1, east-central Red River County (Figs. 2, 4), both of which are only a short distance basinward from the Howard well. The northern limit of the Smackover across Bowie County, therefore, may occur 2–5 miles south of the Arkansas state line (Fig. 2), and approximately the same distance south of the Howard well in the western part of the county. Red shale and anhydrite of the Buckner formation overlie the Smackover in Bowie County.

A description of the Smackover and part of the underlying Eagle Mills formations follows.

SUMMARIZED DESCRIPTION OF SMACKOVER AND PART OF EAGLE MILLS FORMATIONS

Barnsdall Oil Company and Sohio Petroleum Company's J. R. Greenwood No. 1, Eylau field, Lewis T. King Survey, Bowie County, Texas; derrick-floor elevation 306 feet; total depth 8,188 feet in Eagle Mills formation (information supplied by Sohio Petroleum Company).

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
SMACKOVER FORMATION		
Limestone, gray, dense, and non-oölitic at top, öolitic and partly porous below, sandy and dolomitic in lower part (cored)	7,646–70	16
Sandstone, gray, non-porous, calcareous, reddish at base, and sandy limestone; quartzitic texture in lower part (cored)	7,691	11
No record of samples	7,687	16
Sandstone, pink and gray, very fine-grained, partly porous, containing anhydrite in fractures; black laminations (cored)	7,692	5
Mudstone, reddish purple, altered, very hard, streaked with green (cored)	7,697	5
No record of samples	7,712	15

Lithologic Character	Depth (Feet)	Thickness (Feet)
Siltstone, dark reddish brown, hard, partly chloritic, altered appearance (cored)	7,717	5
Rock of igneous origin?, gray to brown, hard, aphanitic, with reddish brown inclusions up to ¼-inch (cored)	7,722	5
No record of samples	7,788	66
Sandstone, reddish brown and tan, porous at base, quartzitic above (cored)	7,791	3
No record of samples	7,912	121
EAGLE MILLS? FORMATION		
Igneous or metamorphic rock, green to brownish gray, finely crystalline with inclusions of bright reddish brown feldspar?, and a soft light green mineral, lower part mainly dark green, chloritic? (cored)	7,922	10
No record of samples	8,081	159
Sandstone, red and gray, fine-grained, partly porous, altered; anhydrite-filled fractures in lower part (cored)	8,091	10
No record of samples.....Total depth	8,188	

RED RIVER COUNTY

The Smackover is only 150 feet thick in The Texas Company's Solomon No. 1 (Fig. 2), and is absent a short distance updip in the Magnolia Petroleum Company's Henry No. 1 in the west-central part of the county. It thickens to 350 feet in the Tex-Harvey Oil Company's York No. 1, southeastern Red River County, where the upper 60 feet are oölitic, porous limestone, the remainder dense and non-oölitic, resting on redbeds of the Eagle Mills formation. Red shale and anhydrite of the Buckner formation overlie the Smackover in Red River County.

FRANKLIN, TITUS, AND MORRIS COUNTIES

The Smackover contains many layers of dolomitic limestone in all three counties (Figs. 2, 4, 5), but the upper 50–75 feet are oölitic, partly porous limestone. In White and Vaughan's Jackson No. 1, Talco field, northern Franklin County, in which the Smackover was completely penetrated (Fig. 5), it is 457 feet thick and rests on redbeds and salt of the Eagle Mills formation. Shale layers are in the middle part at Talco, and anhydrite in the more dolomitic lower part.

WOOD AND SMITH COUNTIES

In the Humble Oil and Refining Company's McKnight No. 1, southeastern Wood County, the Smackover is 1,540 feet thick, and the upper 750 feet contains oölitic layers. Information supplied by the Humble Oil and Refining Company shows that the oölitic part largely lacks porosity. It is the writer's belief that the exceptionally thick oölitic part of the Smackover in this well represents the offshore equivalent of the Buckner formation, and that interfingering of the Buckner and Smackover occurs in the Humble's Wright and Searcy wells farther north in Morris and Titus counties. In the McKnight well the oölites occur at different levels and are disseminated in a matrix of dense limestone rather than in a closely packed condition.

The Smackover is 1,490 feet thick in the Sinclair-Prairie Oil Company's

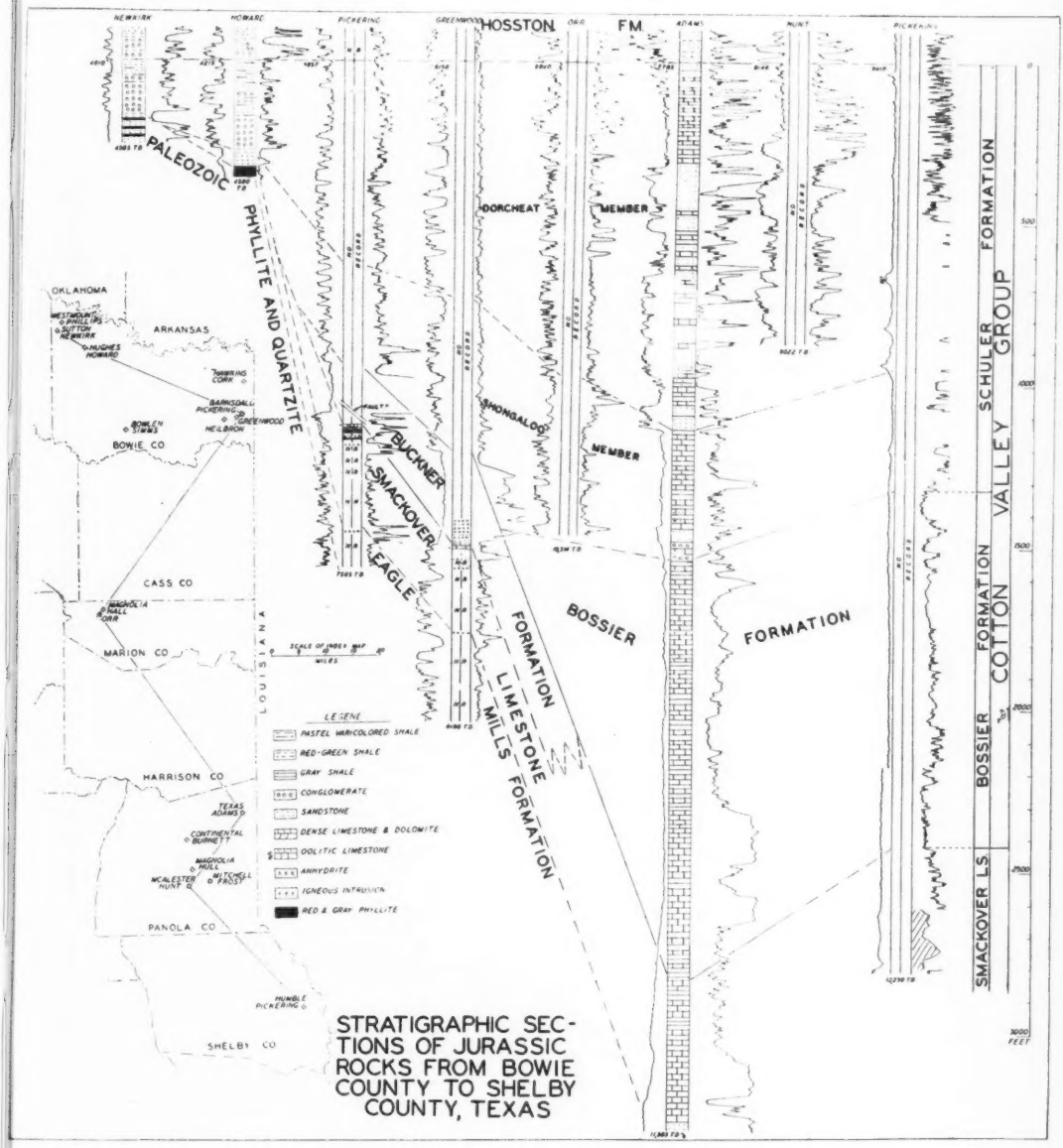
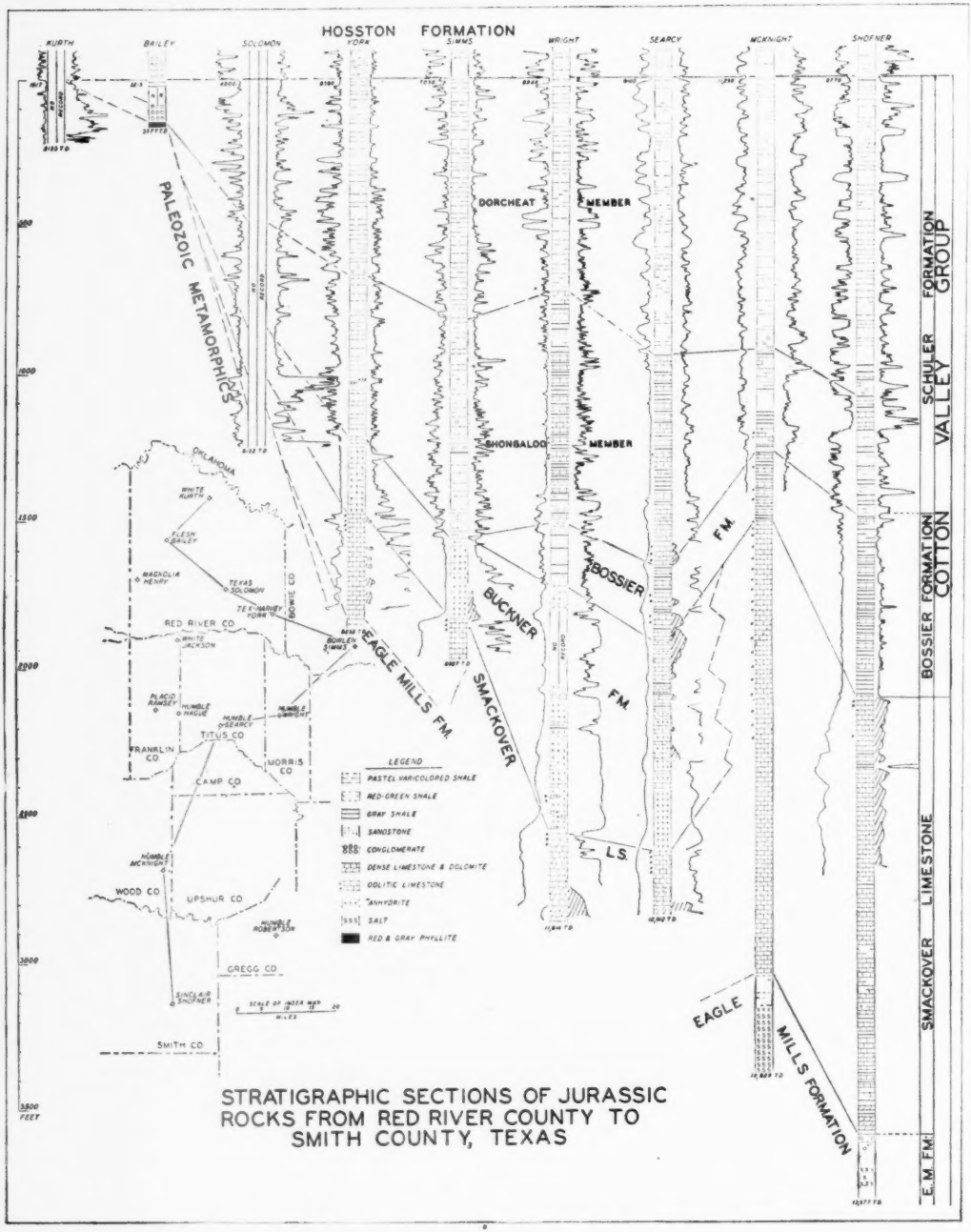

HOSSTON
FM
PALEOZOIC
PHYLLITE AND QUARTZITE
DORCHEAT
MEMBER
SHONGALOO
MEMBER
BUCKNER
SMACKOVER
EAGLE
FORD
FORMATION
LIMESTONE
MILLS
FORMATION
BOSSIER
FORMATION
SCHULER
FORMATION
VALLEY
GROUP
COTTON
VALLEY
BOSSIER
FORMATION
SMACKOVER L.S.
OKLAHOMA
ARKANSAS
BOWIE CO
CASS CO
MARION CO
HARRISON CO
PANOLA CO
SHELBY CO
LOUISIANA
LEGEND
PASTEL VARICOLORED SHALE
RED-GREEN SHALE
GRAY SHALE
CONGLOMERATE
SANDSTONE
DENSE LIMESTONE & DOLOMITE
OOLITIC LIMESTONE
ANHYDRITE
IGNEOUS INTRUSION
RED & GRAY PHYLLITE
STRATIGRAPHIC SECTIONS OF JURASSIC ROCKS FROM BOWIE COUNTY TO SHELBY COUNTY, TEXAS

FIG. 3



STRATIGRAPHIC SECTIONS OF JURASSIC ROCKS FROM RED RIVER COUNTY TO SMITH COUNTY, TEXAS

FIG. 4

Shofner No. 1, Chapel Hill field, east-central Smith County (Figs. 2, 4). The upper 150 feet of the formation are oölitic, and below the middle are many sandy layers. The reason for the occurrence of sandy layers so far from the presumed northerly source of Jurassic clastic sediments merits further study.

The Bossier formation overlies the Smackover in the McKnight and Shofner wells. Clastics and salt of the Eagle Mills formation underlie the Smackover in the McKnight well; clastics, conglomeratic at the top, and with anhydrite layers but no known salt underlie the Smackover in the Shofner well.

Some of the geologists who have studied the two wells believe that part or all of the limestones here called the Smackover formation belong in the lower part of the Cotton Valley group.

HUNT COUNTY

The Smackover formation consists of only 30 feet of reddish, oölitic, sandy limestone in the American Liberty Oil Company's McNatt No. 1, west-central Hunt County, where it passes gradationally downward into redbeds of the Eagle Mills formation. It is absent a few miles farther north in the Humble Oil and Refining Company's Anderson No. 1, where the Buckner formation rests on Paleozoic phyllites. The Smackover is 484 feet thick in the Humble's Graham No. 1, south-central Hunt County, where the upper 90–100 feet are oölitic, dolomitic, and partly porous. The formation is underlain by a few feet of sandy red shale and salt of the Eagle Mills.

LIMESTONE, FREESTONE, AND ROBERTSON COUNTIES

South of Hunt County the following wells had, in 1947, completely penetrated the Smackover formation: (1) Stanolind Oil and Gas Company's Norris No. 1, southwestern Limestone County; (2) The Texas Company's White No. 1, central Freestone County; (3) Cockburn and Zephyr Oil Company's Buie No. 1, eastern Falls County; (4) Cockburn's Gillam No. 1, eastern Falls County; and (5) Quintana's Spahn No. 1, northern Gonzales County. Detailed information on either of the last two wells was not available. Few data were available on the Smackover in the Buie well, but information supplied by the Magnolia Petroleum Company suggests that the Smackover is less than 50 feet thick, consists of tan, partly oölitic limestone, rests on Paleozoic? phyllite, and is overlain by basal conglomeratic sandstones of the Schuler formation. The Nu-Enamel Oil Company's Erskine No. 1, southwestern Limestone County, penetrated 91 feet of non-oölitic, recrystallized, partly porous limestone.

In the Norris well, the Smackover is 460 feet thick, is oölitic and porous in the upper 50 feet, contains dolomitic layers throughout, shale and anhydrite in its middle part, and is sandy at the base (Imlay, 1943, p. 1443). Salt of the Eagle Mills underlies the sandy limestone. The Smackover in the White well is 1,250 feet thick, contains scattered oölites in a dense matrix in the upper 75 feet, thin layers of anhydrite in its middle part, and becomes increasingly dolomitic down-

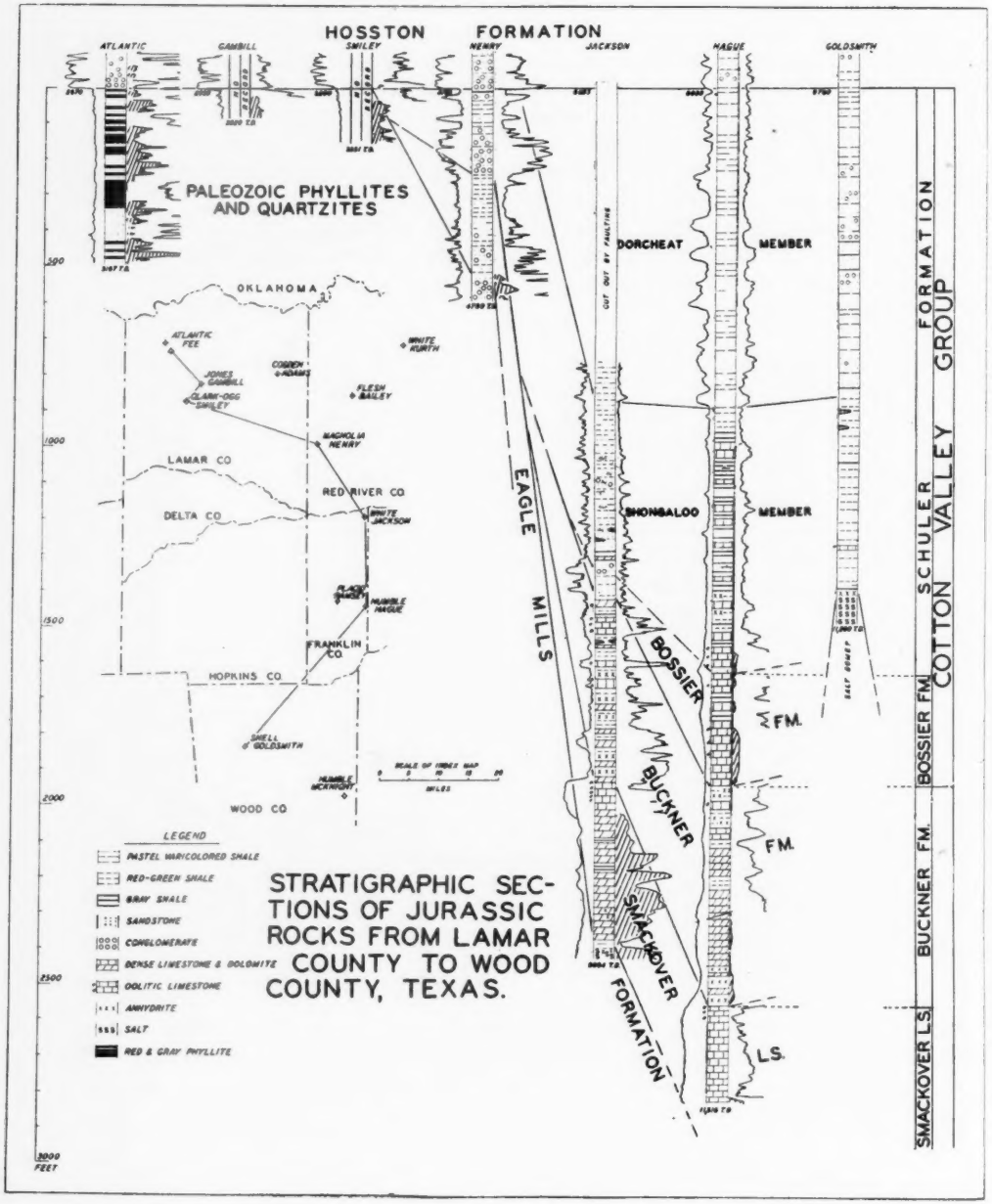

HOSSTON FORMATION
ATLANTIC
GAMBILL
SMILEY
HENRY
JACKSON
HAGUE
GOLDSMITH
PALEOZOIC PHYLLITES AND QUARTZITES
OKLAHOMA
ATLANTIC FEE
JONES GAMBILL
CLARK-OGG SMILEY
COBDEN ADAMS
WHITE KURTH
FLESH BAILEY
MAGNOLIA HENRY
LAMAR CO
RED RIVER CO
DELTA CO
WHITE JACKSON
HUMBLE HAGUE
FRANKLIN CO.
HOPKINS CO.
SHELL GOLDSMITH
HUMBLE WICHHORST
WOOD CO
SCALE OF INDEX MAP
MILES
LEGEND
PASTEL VARICOLORED SHALE
RED-GREEN SHALE
GRAY SHALE
SANDSTONE
CONGLOMERATE
DENSE LIMESTONE & DOLOMITE
OOLITIC LIMESTONE
ANHYDRITE
SALT
RED & GRAY PHYLLITE
STRATIGRAPHIC SECTIONS OF JURASSIC ROCKS FROM LAMAR COUNTY TO WOOD COUNTY, TEXAS.
CUT OUT BY FAULTING
DORCHEAT
MEMBER
SHONGALOO
MEMBER
EAGLE MILLS
BOSSIER
BUCKNER
SMACKOVER
FORMATION
FM.
FM.
LS.
SALT HORIZ
SMACKOVER LS.
BUCKNER FM.
BOSSIER FM.
SCHULER FORMATION
COTTON VALLEY GROUP
500
1000
1500
2000
2500
3000 FEET

FIG. 5

ward (Fig. 7). It rests on fine-grained gray sandstone of the Eagle Mills formation.

A. G. Hill's Anderson No. 1, northwestern Robertson County, penetrated 320 feet of the Smackover formation that is mostly finely crystalline, non-porous limestone, interbedded with gray shale, and is sparsely oölitic 100 feet below the top.

BUCKNER FORMATION

The sequence of red shale, anhydrite, and dense varicolored dolomitic limestone overlying the Smackover formation in southern Arkansas and parts of northernmost Louisiana has been named the Buckner formation (Weeks, 1938, p. 966). Descriptions of the stratigraphy of the Buckner as disclosed by drilling to 1943 have been made by Weeks (1938) and Imlay (1940, 1943). Graphic sections, but not detailed discussion, of the Buckner in many wells were presented by Swain (1944) and by the Shreveport Geological Society (1945). Recent drilling in Arkansas and Louisiana has disclosed important new facts about Buckner stratigraphy, but discussion of them is not attempted here.

BOWIE COUNTY

In the East Texas border area, the Buckner formation occurs in all except the northernmost part of Bowie County, but is absent in Marion, Panola, and Shelby counties (Figs. 2, 3). The formation is absent, presumably as a result of removal by pre-Schuler erosion, in Hughes' Howard No. 1 and other wells in northwestern Bowie County, but is 220 feet thick in Hawkins' Cork No. 1, 5 miles northwest of Texarkana, in the eastern part of the county. There and in several wells in the eastern and central parts of the county it consists of red shale and anhydrite above, massively bedded anhydrite below, and is up to 300 feet thick (Figs. 3, 4). The formation probably wedges out southward in northern or central Cass County, as it is absent in Norton's Payne No. 1, Rodessa field, Caddo Parish, Louisiana, adjacent to southern Cass County.

RED RIVER, FRANKLIN, TITUS, AND MORRIS COUNTIES

The Buckner occurs in approximately the southern third of Red River County, where it is as much as 260 feet thick. In this area it contains less anhydrite than elsewhere, as shown in The Texas Company's Solomon No. 1, 9 miles southeast of Clarksville (Fig. 4). The formation is thick in Franklin, Titus, and Morris counties, where it contains layers of dolomite and oölitic limestone that are believed to represent interfingering with the upper part of the Smackover formation. Representative sections of it in this area are here described.

SUMMARIZED DESCRIPTION OF BOSSIER, BUCKNER, AND PART OF SMACKOVER FORMATIONS

Humble Oil and Refining Company's H. N. Wright No. 1, Samuel Storey Survey, Morris County, Texas; derrick-floor elevation 388 feet; total depth 11,814 feet in Smackover formation.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
BOSSIER FORMATION		
Sandstone, gray and white, fine- to medium-grained, slightly porous, having salt-and-pepper appearance because of dark chert grains; interbedded dark gray shale; trace of asphalt 10,460–70 feet	10,445–10,570	125
Sandstone, light red, very fine- and fine-grained, containing light green clayey grains	10,670	100
BUCKNER FORMATION		
Sandstone, gray, fine-grained, non-porous, interbedded white anhydrite and greenish gray to red shale	10,700	30
No record of samples	11,000	300
Anhydrite, white, finely crystalline, interbedded light gray, dense, argillaceous, dolomitic limestone and red shale	11,030	30
Limestone, dark gray	11,040	10
Shale, red, and interbedded white anhydrite	11,055	15
Anhydrite, white, finely crystalline, thick-bedded, interbedded greenish gray and red shale	11,130	75
Shale, dark gray, silty; interbedded dark gray, dense dolomitic limestone	11,180	50
Anhydrite, white and pink, dense to finely crystalline; interbedded gray and greenish gray, argillaceous, dense, dolomitic limestone; minor amounts of red and greenish gray shale; casts and traces of crystalline halite 11,360–80	11,510	330
SMACKOVER FORMATION		
Limestone, grayish brown, fairly porous, oölitic, recrystallized, dolomitic, partly asphaltic	11,540	30
Limestone, grayish brown, finely crystalline, dolomitic, non-oölitic, slightly asphaltic	11,610	70
Limestone, light gray, dense to finely crystalline. . . . . Total depth	11,814	

SUMMARIZED DESCRIPTION OF BUCKNER AND PART OF SMACKOVER FORMATIONS

Humble Oil and Refining Company's J. F. Hague No. 1, J. P. Riddle Survey, Franklin County, Texas; derrick-floor elevation 422 feet; total depth 11,516 feet in Smackover formation; information supplied by Humble Oil and Refining Company.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
BUCKNER FORMATION		
Anhydrite, white, massively bedded	10,626–60	34
Limestone; gray, partly dolomitic and oölitic	10,690	30
Shale, green and red, containing anhydrite	10,740	50
Limestone, gray, dense, thick-bedded	10,770	30
Shale, green and red, sandy	10,790	20
Dolomite, gray and greenish gray, thick-bedded	10,880	90
Shale, green and red	10,920	40
Limestone, gray, dolomitic, and anhydrite, thick-bedded; lower 150 feet predominantly anhydrite	11,236	316
SMACKOVER FORMATION		
Limestone, gray, porous, cellular, crystalline, oölitic in middle part	11,320	84
Limestone, gray, finely crystalline non-porous, becoming denser in lower part	11,460	140
Limestone, gray, granular, partly porous	11,500	40
Limestone, dark gray, dense, sandy in lower part. . . . . Total depth	11,516	

SUMMARIZED DESCRIPTION OF BOSSIER, BUCKNER, SMACKOVER, AND PART OF EAGLE MILLS FORMATIONS

White and Vaughan's W. H. Jackson No. 1, J. E. Hopkins Survey, 1 mile west of Talco, Franklin County, Texas; derrick-floor elevation 354 feet; total depth 9,080 feet in Eagle Mills formation.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
BOSSIER FORMATION		
Shale, dark gray, hard, silty	8,008–25	17
Sandstone, red, fine- to medium-grained, argillaceous	8,032	7
Shale, red, silty	8,045	13
Sandstone, bright red, fine-grained, salty, argillaceous	8,060	15
BUCKNER FORMATION		
Shale, mottled red and green at top, gray at base	8,098	38
Sandstone, gray and light red, fine- to coarse-grained, cemented by dolomite; interbedded gray and red shale	8,120	22
Limestone, light gray, dense and finely crystalline, dolomitic, containing black oölites	8,175	55
Shale, mottled red and green, in part with anhydrite and light greenish gray, dolomitic, limestone	8,250	75
Limestone, light gray, dense, dolomitic, partly oölitic	8,270	20
Shale, red, silty, containing thin layers of anhydrite and dolomitic limestone	8,300	30
Limestone, light gray, oölitic, dolomitic; white anhydrite	8,320	20
Shale, red, sandy, with nodular white anhydrite and argillaceous dolomite	8,365	45
Limestone, gray, dense to finely crystalline, dolomitic, thick-bedded; interbedded white finely crystalline anhydrite	8,573	208
SMACKOVER FORMATION		
Dolomite, brown, porous, fine to coarsely crystalline, containing spherical cavities representing dissolved oölites; spotted brown oil stain	8,630	57
Limestone, gray, dense to finely crystalline, dolomitic, non-oölitic; traces of brown oil stain	8,680	50
Limestone, gray, dense, dolomitic, with splintery fracture, partly argillaceous with layers of red shale, dark gray shale and anhydrite; laminated in lower part	9,030	350
EAGLE MILLS FORMATION		
Shale, light red, sandy, and fine- to medium-grained red sandstone	9,049	19
Salt, top determined by drilling time; samples comprise white anhydrite ..... Total depth	9,080	

HUNT AND KAUFMAN COUNTIES

Wells in southern Hunt and northern Kaufman counties penetrated thick sections of the Buckner (Fig. 6). The Humble Oil and Refining Company's Graham No. 1, Hunt County (Imlay, 1943, p. 1,529), the Ohio Oil Company's Popper No. 1, Hunt County, and the Sun Oil Company's Rutledge No. 1, (Imlay, 1943, p. 1,529), Kaufman County, encountered rock salt in the lower part of the formation. The sequence in the Rutledge well follows.

SUMMARIZED DESCRIPTION OF BUCKNER FORMATION

Sun Oil Company's J. M. Rutledge No. 1, E. Parsons Survey, 7 miles northeast of Terrell, Kaufman County, Texas; derrick-floor elevation 584 feet; total depth 10,058 feet in Smackover formation.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
BUCKNER FORMATION		
Shale, bright red; interbedded white anhydrite	9,260–70	10
No record of samples	9,390	120

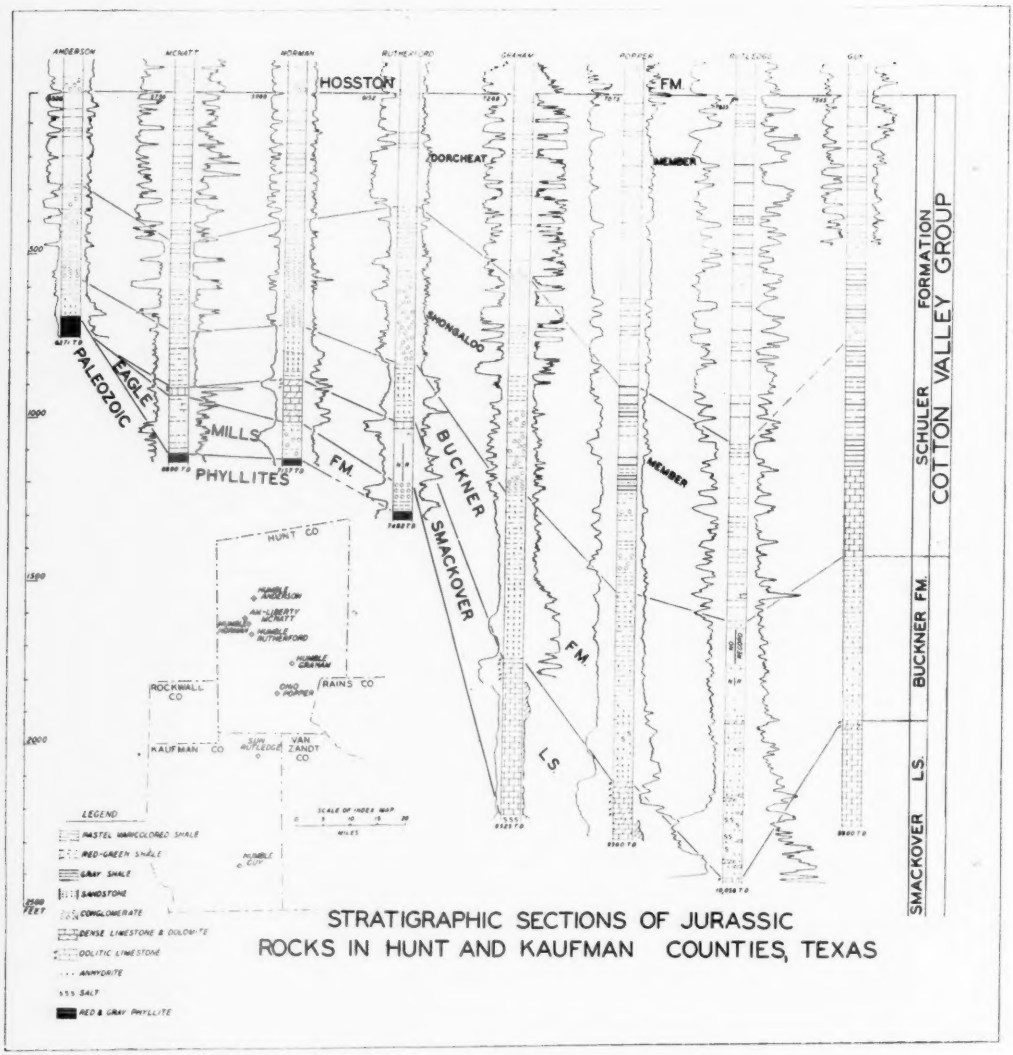

ANDERSON
MCNATT
NORMAN
RUTHERFORD
GRAHAM
HOPPER
RUTLEDGE
GET
HOSSTON
FM.
MEMBER
DORCHEAT
SHONGALOO
BUCKNER
SMACKOVER
FM.
LS.
PALEOZOIC
EAGLE
MILLS
PHYLLITES
FM.
MEMBER
SCHULER FORMATION
COTTON VALLEY GROUP
BUCKNER FM.
SMACKOVER LS.
HUNT CO
ROCKWALL CO
RAINS CO
KAUFMAN CO
VAN ZANDT CO
LEGEND
PASTEL VARICOLORED SHALE
RED-GREEN SHALE
GRAY SHALE
SANDSTONE
CONGLOMERATE
DENSE LIMESTONE & DOLOMITE
OOLITIC LIMESTONE
ANHYDRITE
SALT
RED & GRAY PHYLLITE
FEET
STRATIGRAPHIC SECTIONS OF JURASSIC
ROCKS IN HUNT AND KAUFMAN COUNTIES, TEXAS

FIG. 6

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
Shale, brick red; interbedded layers of white, finely crystalline anhydrite, and fine-grained red sandstone	9,430	40
No record of samples	9,450	20
Shale, anhydrite, and sandstone, as above	9,500	50
No record of samples, cored red and green shale with nodular anhydrite, and greenish gray, dolomitic limestone at several levels	9,640	140
Shale, red and green, mottled; interbedded white anhydrite, and impure dolomitic limestone	9,848	208
Rock salt, colorless to light red, coarsely crystalline, intermixed with red clay and argillaceous dolomite	9,980?	132?
Anhydrite, white, massively bedded; light gray to white, dense, dolomitic limestone; interbedded red and green shale	10,043	63
SMACKOVER FORMATION		
No record of samples, top determined from electrical log.....Total depth	10,058	

FREESTONE, FALLS, LIMESTONE, AND ROBERTSON COUNTIES

In central Freestone County the Buckner formation has its greatest known thickness of 890 feet in The Texas Company's White No. 1. It consists of dark greenish gray, argillaceous limestone and interbedded anhydrite. On the west in central Limestone, Falls, and western Robertson counties the formation is much thinner, consists of sandy redbeds without anhydrite, and is locally absent (Fig. 7).

The basinward limit of the Buckner formation is unknown but its very calcareous character in central Freestone, northeastern Kaufman, and south-central Titus counties suggests that it does not extend much farther downdip from those areas.

Although nowhere in the East Texas basin is there evidence of a gradational relationship between the Buckner and Smackover formations, the two are believed to be conformable. Bates (1942, p. 89) has pointed out the abruptness of the margins of similar evaporite deposits in the Permian of New Mexico, so that interfingering of anhydrite in the lower part of the Buckner with limestone of the Smackover possibly does not occur.

The offshore interfingering of anhydrite and evaporitic dolomitic limestone of the Buckner with oölitic limestones of Smackover type suggests that the latter were developed at the site of, or actually formed, restrictive barriers that were a factor in the deposition of the evaporites. Farther offshore in Buckner time there accumulated the fine-grained calcareous muds of the upper part of the dense limestone that forms the basinward facies of the Smackover. The oölitic limestone of the Smackover formation in its updip occurrences forms, in most places, less than 100 feet of its uppermost beds, but in a downdip well, the Humble's McKnight No. 1, oölites are scattered sparsely through the upper 750 feet of dense Smackover. This evidence supports assignment of a Buckner age to the upper part of the more basinward Smackover. There may have been occasional shoaling of the water offshore from the oölite-forming areas of the Buckner or, more plausibly, some of the Buckner oölites were reworked seaward by wave action.

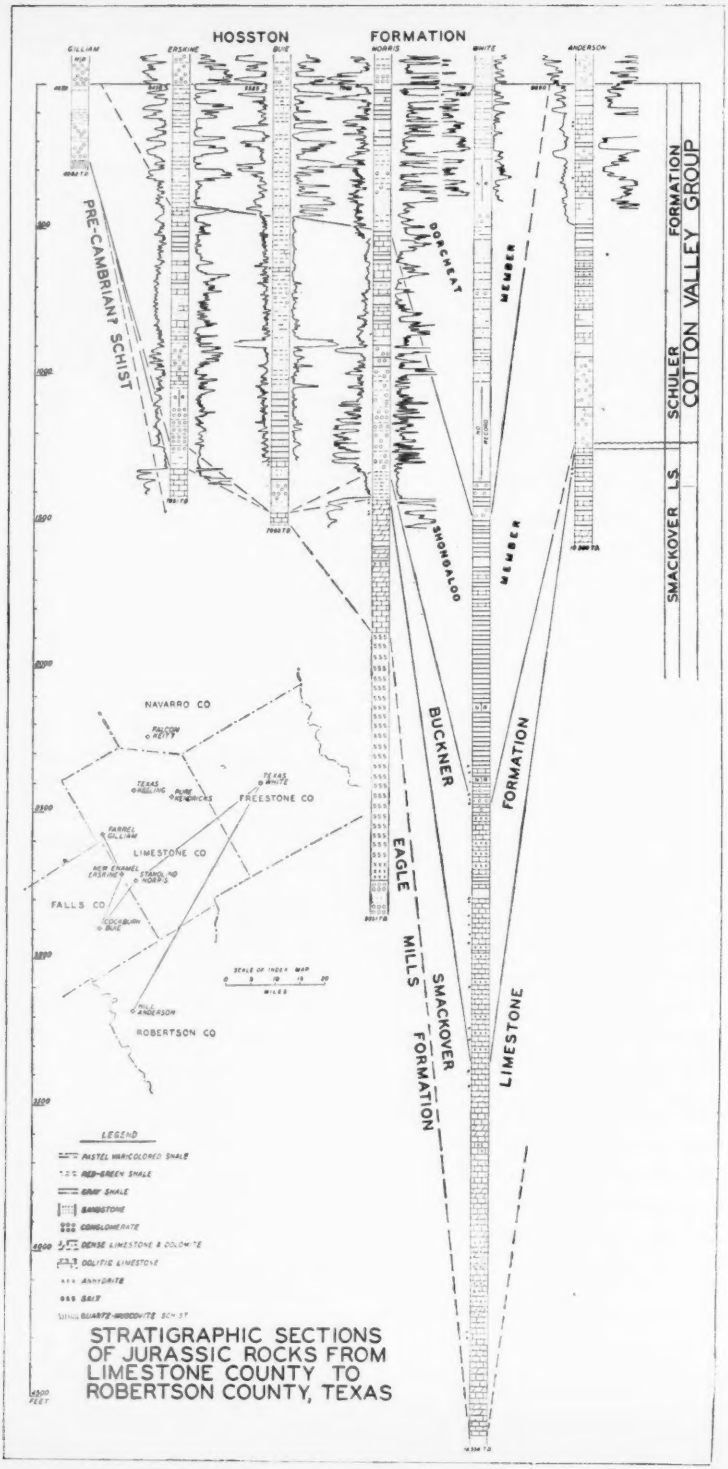

HOSSTON
FORMATION
GILLIAM
ERSKINE
BLUE
NORRIS
WHITE
ANDERSON
PRE-CAMBRIAN? SCHIST
DORCHEAT
MEMBER
SHONGALOO
MEMBER
SCHULER
FORMATION
SMACKOVER L.S.
COTTON VALLEY GROUP
BUCKNER
FORMATION
EAGLE MILLS
FORMATION
SMACKOVER
LIMESTONE
NAVARRO CO
FREESTONE CO
LIMESTONE CO
FALLS CO
ROBERTSON CO
LEGEND
PASTEL VARICOLORED SHALE
RED-GREEN SHALE
GRAY SHALE
SANDSTONE
CONGLOMERATE
DENSE LIMESTONE & DOLOMITE
OOLITIC LIMESTONE
ANHYDRITE
SALT
QUARTZ-MUSCOVITE SCHIST
FEET
STRATIGRAPHIC SECTIONS
OF JURASSIC ROCKS FROM
LIMESTONE COUNTY TO
ROBERTSON COUNTY, TEXAS

FIG. 7

BOSSIER FORMATION

The Bossier formation, consisting of black shales and impure limestones containing ammonites in its type locality, lies between the Buckner and Smackover formations below, and the Schuler formation above, in northern Louisiana and southernmost Arkansas (Swain, 1944, p. 585). Recent drilling has resulted in new concepts about the Bossier and associated strata that are currently under consideration by geologists of that region.

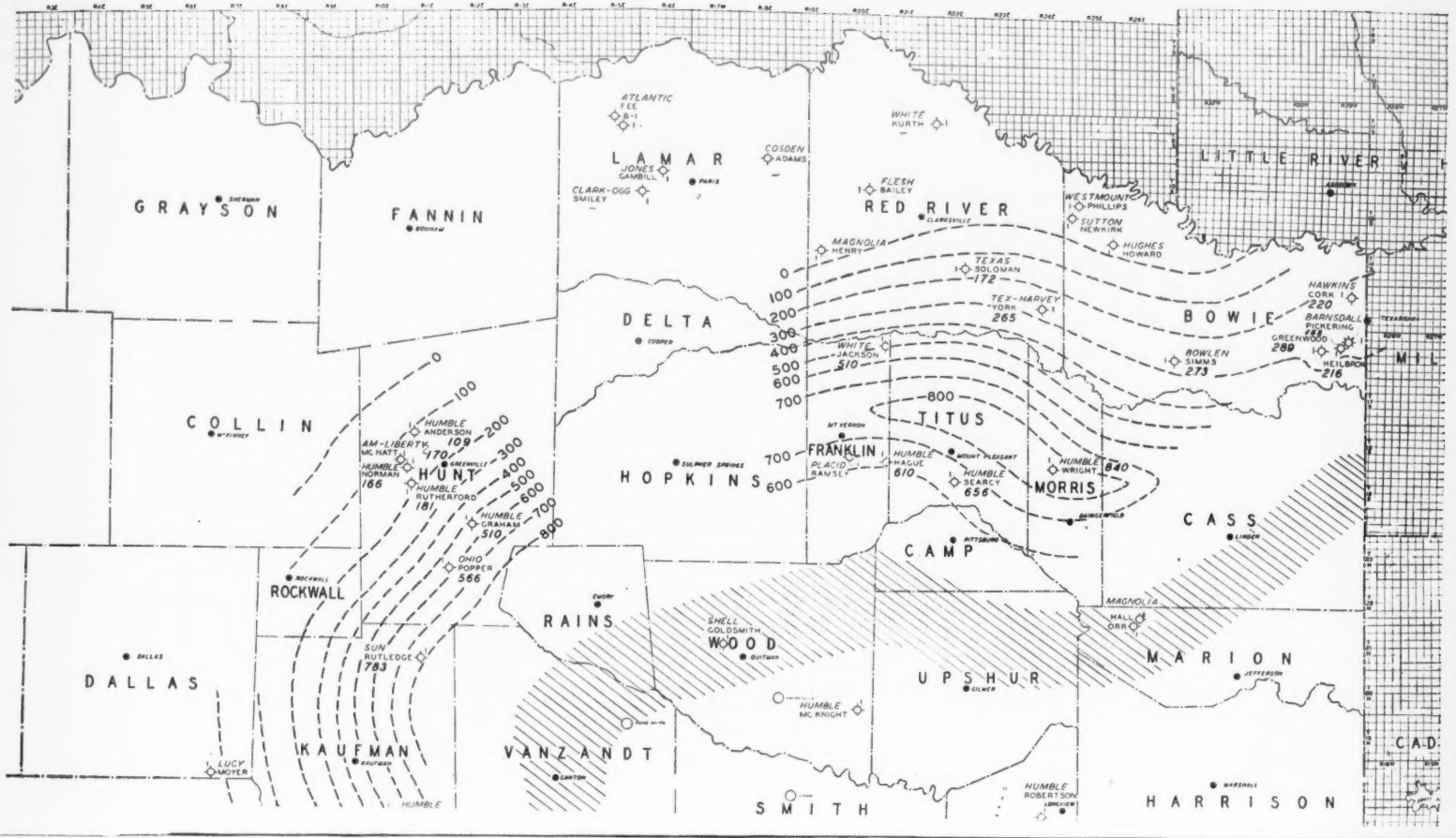
The Bossier formation has been penetrated by drilling in Panola, Shelby, Morris, Titus, Franklin, Wood, and Smith counties. Its greatest thickness is in the Sabine uplift where it is 1,300 feet thick in The Texas Company's Adams No. C-1, Panola County, and 1,100 feet thick in the Humble Oil and Refining Company's Pickering No. 1, Shelby County. In these two wells, as in adjacent northwestern Louisiana, the formation consists of dark gray to black shale and impure limestone that rest on the Smackover formation.

In the Sinclair-Prairie Oil Company's Shofner No. 1, Chapel Hill field, Smith County, the Bossier formation is 615 feet thick, consists of dark gray shale and dense limestone with thin beds of sandstone in the upper part, and rests on the Smackover formation. Twenty-eight miles farther north in the Humble's McKnight No. 1, Wood County, it is only 235 feet thick, consists of dark gray shales and partly oölitic limestones resting on the Smackover. It is lithologically similar and is 255 feet thick in the Humble's Searcy No. 1, Titus County, 35 miles north of the McKnight well, but there rests on the thick Buckner formation. A short distance updip a facies change occurs and in the Humble's Wright No. 1, Morris County, the Bossier consists of white sandstone and interbedded gray shale 210 feet thick. It is present in the Humble's Hague No. 1, east-central Franklin County, as 310 feet of partly sandy, oölitic limestone, and dark gray shale. In White and Vaughan's Jackson No. 1, Talco field, northeastern Franklin County, 55 feet of nearshore, possibly non-marine, fine-grained sandstone and red shale represent the Bossier. In all three of the wells the formation rests on a thick sequence of redbeds, anhydrites, and partly oölitic limestones of the Buckner. The Bossier has not been penetrated by drilling west of Wood County, but apparently does not extend far up the western slope of the basin, as wells in eastern Kaufman and central Freestone counties did not encounter it.

The thinning of the formation north of Smith County probably results partly from removal of its upper layers by pre-Schuler erosion, but south of Smith County such an unconformable relationship can not be demonstrated.

SCHULER FORMATION

The Schuler formation is better known than the underlying formations of the Upper Jurassic because more wells have penetrated it. In the present discussion, the broader relationships of the formation will be considered first, followed by a description of the two members, and finally, detailed descriptions of several representative sections in the East Texas area.


GRAYSON
FANNIN
LAMAR
ATLANTIC FEE B-1
JONES GAMBILL 1
CLARK-OGG SMILEY 1
COSDEN ADAMS
WHITE KURTH 1
FLESH BAILEY
RED RIVER
LITTLE RIVER
WESTMOUNT PHILLIPS
SUTTON NEWKIRK
HUGHES HOWARD
MAGNOLIA HENRY
TEXAS SOLOMAN 172
TEX-HARVEY YORK 265
DELTA
BOWIE
HAWKINS CORK 1 220
BARNSDALL PICKERING 188
GREENWOOD 289
HEILBRON 216
BOWLEN SIMMS 273
WHITE JACKSON 510
COLLIN
HUMBLE ANDERSON 109
AM-LIBERTY MC NATT 170
HUMBLE NORMAN 166
HUNT
HUMBLE RUTHERFORD 181
HUMBLE GRAHAM 510
OHIO POPPER 566
TITUS
FRANKLIN
PLACID RAMSEY
HUMBLE HAGUE 610
HUMBLE SEARCY 656
HUMBLE WRIGHT 840
MORRIS
HOPKINS
CASS
CAMP
ROCKWELL
RAINS
SHELL GOLDSMITH
WOOD
MAGNOLIA
HALL ORR
DALLAS
SUN RUTLEDGE 783
UPSHUR
MARION
HUMBLE MC KNIGHT
LUCY MOYER
KAUFMAN
VANZANDT
SMITH
HUMBLE ROBERTSON
HARRISON
CAD
0
100
200
300
400
500
600
700
800

GUY 518
GREGG

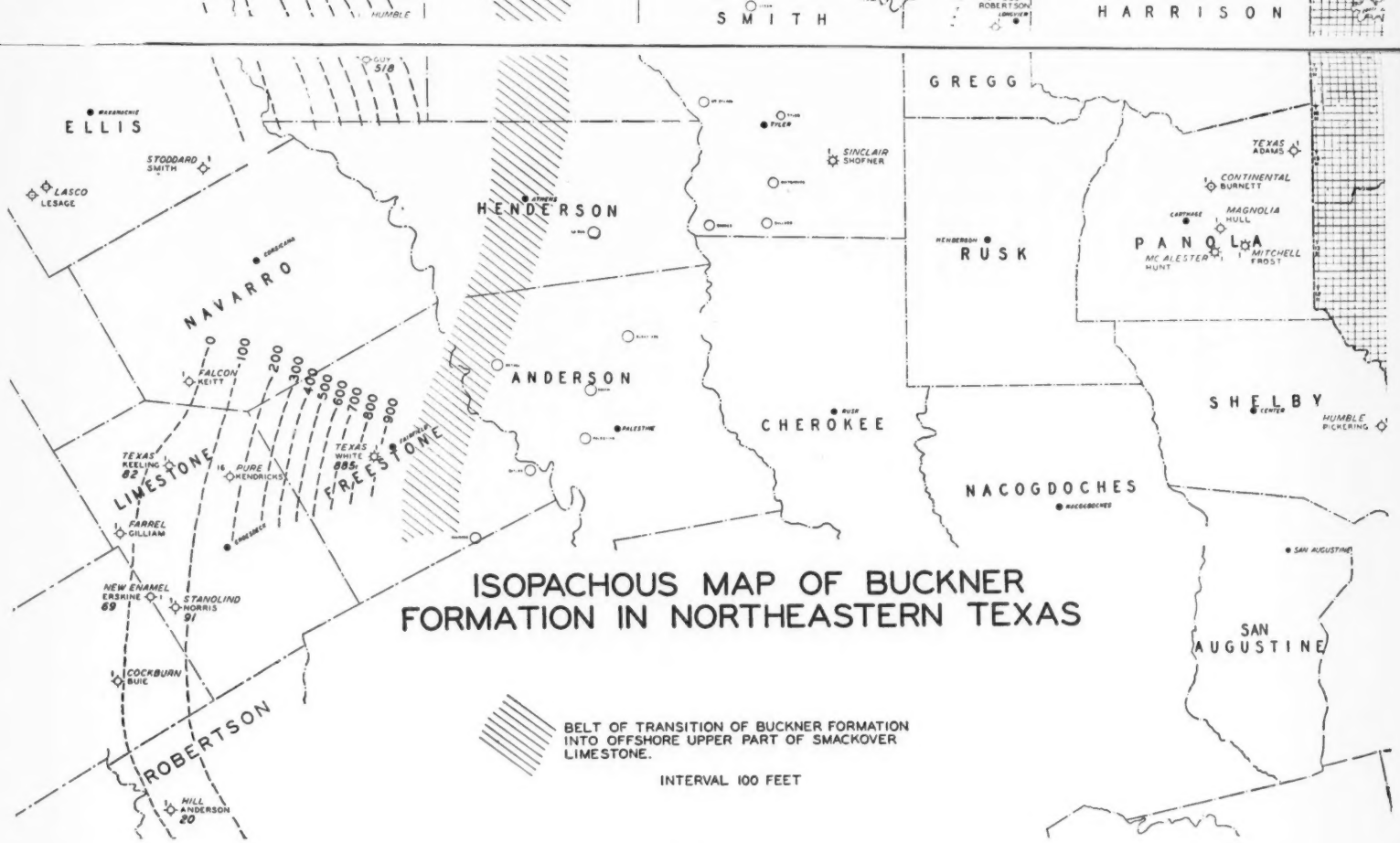

SMITH
HARRISON
ELLIS
STODDARD SMITH
LASCO LESAGE
NAVARRO
HENDERSON
ATHENS
GREGG
TYLER
SINCLAIR SHOFNER
TEXAS ADAMS
CONTINENTAL BURNETT
CARTHAGE
MAGNOLIA HULL
HENDERSON
RUSK
PANOLA
MC ALESTER HUNT
MITCHELL FROST
FALCON KEITT
0
100
200
300
400
500
600
700
800
900
ANDERSON
CHEROKEE
SHELBY
HUMBLE PICKERING
TEXAS KEELING 82
16 PURE KENDRICKS
TEXAS WHITE 885
LIMESTONE
FREESTONE
FARREL GILLIAM
NACOGDOCHES
NEW ENAMEL ERSKINE 69
STANOLIND NORRIS 91
SAN AUGUSTINE
COCKBURN BUIC
ROBERTSON
HILL ANDERSON 20
ISOPACHOUS MAP OF BUCKNER FORMATION IN NORTHEASTERN TEXAS
BELT OF TRANSITION OF BUCKNER FORMATION INTO OFFSHORE UPPER PART OF SMACKOVER LIMESTONE.
INTERVAL 100 FEET

FIG. 8

At the type locality, Schuler oil field, Union County, Arkansas, the Schuler formation (Swain, 1944, p. 594) is 2,090 feet thick, and consists of two members differentiated by color. The upper or Dorcheat member, 1,060 feet thick at Schuler, consists of pale gray and varicolored, fresh- or brackish-water shales and mudstones interbedded with white, mostly porous, fine-grained sandstones. The shales at several horizons contain tiny spherulites of siderite in great abundance. The member maintains this distinctive character throughout most of southern Arkansas, but near the Louisiana state line a change to offshore, gray, shallow-water marine sediments occurs (Swain, 1944, p. 596). The nearshore facies of the lower or Shongaloo member, 1,020 feet thick at Schuler, consists of red silty shales, commonly mottled with green and lacking siderite of the spherulitic type, together with red and white sandstones and conglomerates. A facies change to marine gray shales, sandstones, limestones, and conglomerates occurs, as in the Dorcheat, near the Louisiana state line. Although spherulitic siderite is generally lacking in the Shongaloo, this material is present in some wells in strata lithologically similar to the Dorcheat in the upper part of the Shongaloo, presumably as a result of interfingering between the two members.

The Schuler formation exceeds 2,300 feet in Miller, Columbia, and Union counties, Arkansas, and Union Parish, Louisiana, within a belt north of its change in facies (Swain, 1944, p. 596). The gradual thinning southward in Louisiana is believed to be the result of decreasing offshore deposition of sediments.

Wherever it has been completely penetrated in northern Louisiana, the Schuler rests in part unconformably on the middle and upper Kimmeridgian Bossier formation (Swain, 1944, p. 599; Imlay, 1945). In southern Arkansas, the Schuler oversteps the Bossier and rests on the Buckner, Smackover, and Eagle Mills formations. The Schuler is overlain in normal sequence by early Lower Cretaceous red shales, sandstones, and conglomerates of the Hosston formation. In part of southeastern Arkansas, pre-Upper Cretaceous erosion removed the Hosston so the Upper Cretaceous rests on the Schuler and older formations (Imlay, 1940, Pl. III).

In northeastern Texas, the Schuler formation has been penetrated by drilling in the following counties: Bowie, Marion, Panola, Shelby, Red River, Morris, Titus, Franklin, Gregg, Wood, Smith, Hunt, Kaufman, Ellis, Navarro, Freestone, Limestone, Falls, and Robertson.

The northern limit of the Schuler formation has not been accurately defined by drilling. In Bowie County (Fig. 3), it probably disappears near the northwestern corner, the boundary apparently passing through southernmost Oklahoma into Little River County, Arkansas. In Red River County, Texas, the boundary passes 6–8 miles north of Clarksville, and probably crosses Lamar County a few miles south of Paris. On the southwest the limit is uncertain. The formation apparently is absent in Lucy and Guiberson's Moyer No. 1, southeastern Dallas County, but is 342 feet thick south in Stoddard's Smith No. 1,

Ellis County. It is absent in the two Lasco-Lesage wells southwest of Waxahachie. South of Ellis County its westward limit is unknown, but may be as indicated in Figure 1.

In the middle part of the East Texas basin the Schuler and older strata have not been penetrated, but it is reasonable to suppose that the formation underlies Delta, Hopkins, Rains, Van Zandt, Henderson, Anderson, Cherokee, and Nacogdoches counties, as well as other counties on the south.

The thickness variations of the Schuler formation in northeastern Texas are shown in Figure 9. As in southern Arkansas and northern Louisiana (Swain, 1944, p. 596), the greatest thickness generally occurs where the sediments change from non-marine or brackish-water redbeds to offshore marine strata. In East Texas, these relationships are modified by the Sabine arch which probably was a platform area during the Upper Jurassic. As a result the Schuler does not change greatly in thickness over a large area occupied by the East Texas border counties.

The thickest known occurrence of the Schuler, possibly excepting that encountered in a well in Clark County, Alabama, is 2,490 feet in The Texas Company's White No. 1 well, Freestone County, Texas.

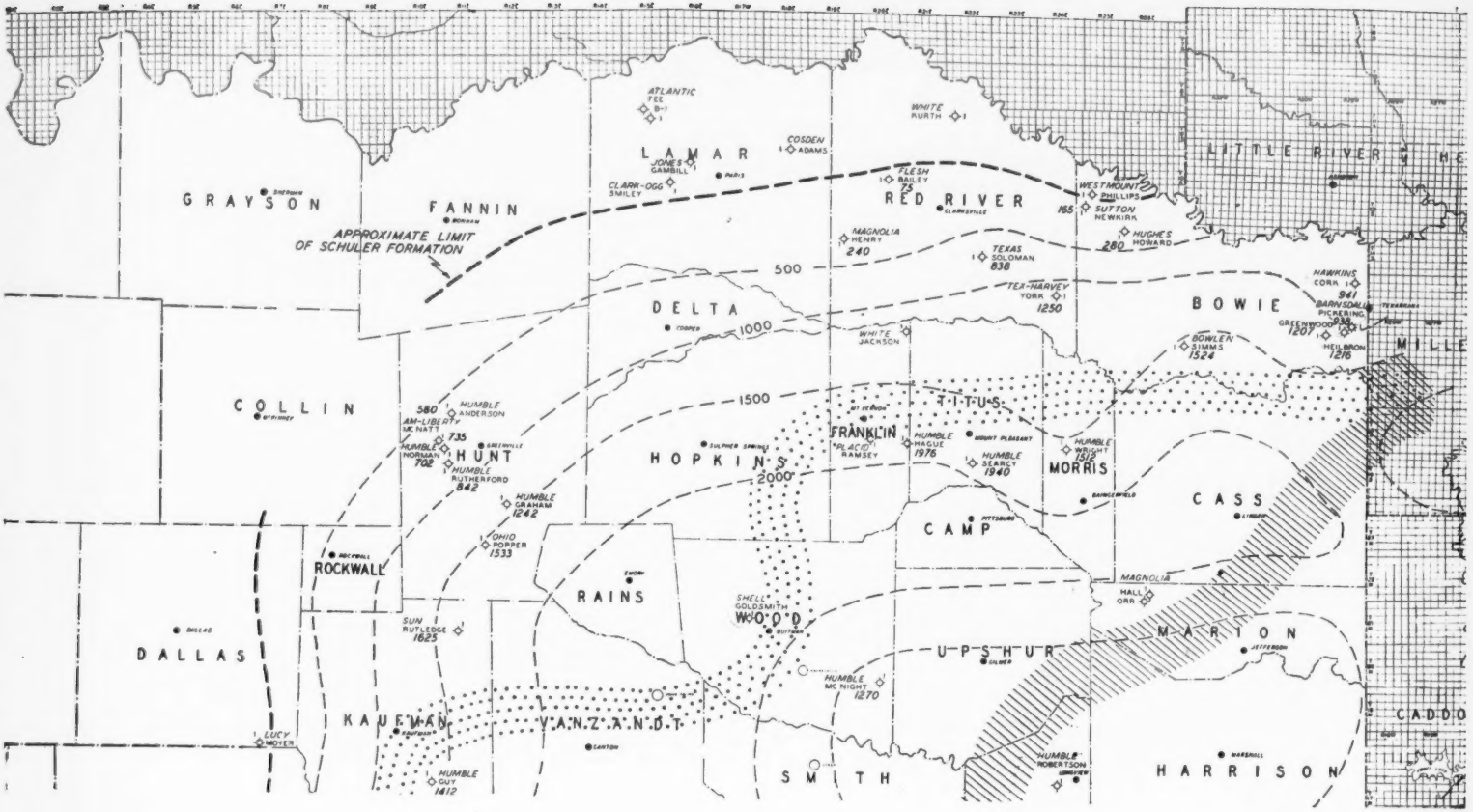
SHONGALOO MEMBER

The lower member of the Schuler formation in the East Texas basin consists of non-marine red and green silty shales, red and white sandstones and conglomerates that grade basinward into marine, partly conglomeratic sandstones, dark gray shales, and limestones. The upper part of the member in both the non-marine and the marine facies contains relatively more shale than the overlying basal layers of the Dorcheat member. In the non-marine facies the writer determined the top of the Shongaloo at the appearance in drill-cuttings of dominantly red (or red and green, mottled) shales, which are in contrast to the more varicolored, lighter shales of the Dorcheat.

The change of facies in the Shongaloo occurs farther updip than does that of the overlying Dorcheat member, whereas in Arkansas the non-marine facies of both members extends equally far downdip.

The Shongaloo member is 900 feet thick in The Texas Company's White No. 1, Freestone County, but averages less than 600 feet in most of the East Texas basin. During Shongaloo time and part of Dorcheat time the shoreline probably was near the Llano source area, judged by the thick marine sections in Freestone, Robertson, and central Limestone counties, and by the rapid westward gradation of the marine units into non-marine coarse clastics. In central Freestone County the basal part of the Shongaloo contains oölitic limestones and thin conglomeratic beds that suggest shallow water and a near-by source of coarse clastics, but the overlying layers consist of dark gray shale and argillaceous dense limestone that are probably of deeper-water origin.

Around the northern margin of the East Texas basin, the Shongaloo member is onlapped by the Dorcheat member which rests on Paleozoic rocks. This reflects


GRAYSON
FANNIN
LAMAR
RED RIVER
LITTLE RIVER
DELTA
BOWIE
COLLIN
HUNT
HOPKINS
FRANKLIN
TITUS
MORRIS
CASS
CAMP
ROCKWALL
RAINS
WOOD
UPSHUR
MARION
DALLAS
KAUFMAN
VAN ZANDT
SMITH
HARRISON
CADDO
MILLE
APPROXIMATE LIMIT OF SCHULER FORMATION
500
1000
1500
2000
ATLANTIC FEE B-1 1
COSDEN ADAMS 1
WHITE RURTH 1
JONES GAMBILL 1
CLARK-OGG SMILEY
FLESH BAILEY 1 75
WESTMOUNT PHILLIPS
SUTTON NEWKIRK 165
MAGNOLIA HENRY 240
TEXAS SOLOMAN 838
HUGHES HOWARD 280
TEA-HARVEY YORK 1 1250
HAWKINS CORA 1 941
BARNSDALL PICKERING 936
GREENWOOD 1207
HEILBRON 1216
WHITE JACKSON
BOWLEN SIMMS 1524
580 HUMBLE AM-LIBERTY MC NATT 1
735 HUMBLE NORMAN 702
HUMBLE ANDERSON
HUMBLE RUTHERFORD 542
HUMBLE GRAHAM 1242
OHIO POPPER 1533
"PLACID" RAMSEY
HUMBLE HAGUE 1976
HUMBLE SEARCY 1940
HUMBLE WRIGHT 1512
MAGNOLIA HALL ORR
SHELL GOLDSMITH
SUN 1 RUTLEDGE 1625
HUMBLE MC NIGHT 1270
HUMBLE GUY 1412
HUMBLE ROBERTSON
LUCY MOYER

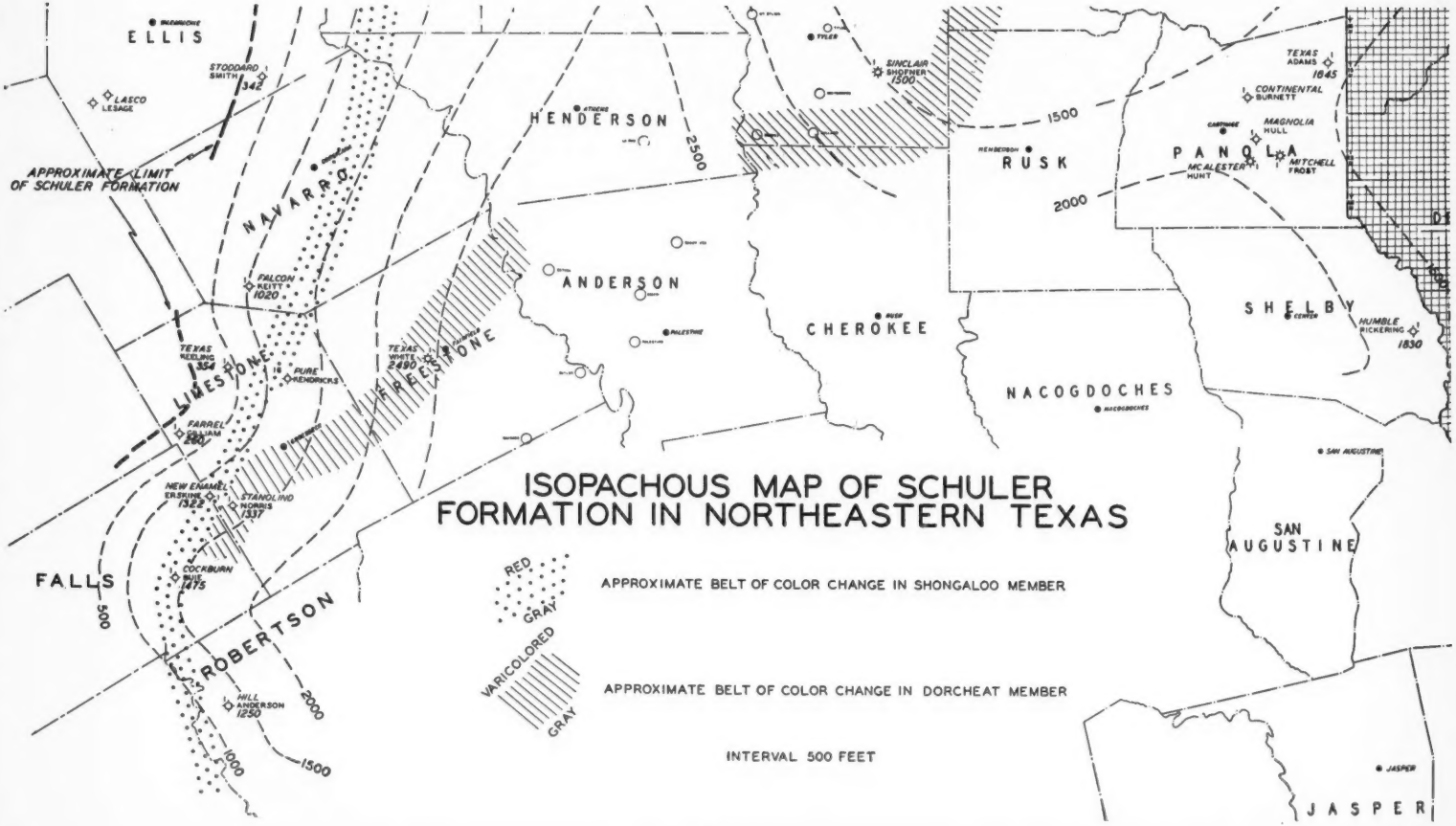

ELLIS
STODDARD SMITH 342
LASCO LESAGE
APPROXIMATE LIMIT OF SCHULER FORMATION
NAVARRO
FALCON REITT 1020
TEXAS KEELING 354
PURE HENDRICKS
LIMESTONE
FARREL GRAHAM 280
NEW ENAMEL ERSKINE 1322
STANOLIND NORRIS 337
COCKBURN PAVE 1475
FALLS
500
ROBERTSON
HILL ANDERSON 1250
2000
1500
1000
HENDERSON
2500
TEXAS WHITE 2490
FREESTONE
ANDERSON
CHEROKEE
SINCLAIR SHOFNER 1500
TYLER
1500
RUSK
2000
TEXAS ADAMS 1645
CONTINENTAL BURNETT
MAGNOLIA HULL
PANOLA
MC ALESTER HUNT
MITCHELL FROST
SHELBY
HUMBLE RICKERING 1830
NACOGDOCHES
SAN AUGUSTINE
JASPER
ISOPACHOUS MAP OF SCHULER FORMATION IN NORTHEASTERN TEXAS
RED GRAY
APPROXIMATE BELT OF COLOR CHANGE IN SHONGALOO MEMBER
VARICOLORED GRAY
APPROXIMATE BELT OF COLOR CHANGE IN DORCHEAT MEMBER
INTERVAL 500 FEET

FIG. 9

PLATE I. Thin sections of Upper Jurassic sedimentary rocks in southern Arkansas, northern Louisiana, and northeastern Texas.

FIG. 1.—Thin section of gray, arenaceous, feldspathic, calcareous shale; Shongaloo member of Schuler formation; Phillips Petroleum Company, Kendrick No. 1, Bossier Parish, Louisiana; core 6,382–97 feet; × nicols; ×25.

FIG. 2.—Thin section of medium-crystalline dolomite; Buckner formation; White and Vaughan's Jackson No. 1, Franklin County, Texas; core sample, 7,912–13 feet; × nicols; ×25.

FIG. 3.—Thin section of fine- to coarse-grained, gray, angular to subrounded, calcareous sandstone, containing grains of quartzite and novaculite; Shongaloo member of Schuler formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; core 6,367–82 feet; × nicols; ×25.

FIG. 4.—Thin section of greenish gray, very finely arenaceous shale, typical of waxy shales of Dorcheat member of Schuler formation; Ohio Oil Company's Taylor No. 15, Claiborne Parish, Louisiana; core 7,682–7,707 feet; × nicols; ×25.

FIG. 5.—Thin section of fine- to coarse-grained, argillaceous, gray, angular to subangular sandstone, containing grains of novaculite; Shongaloo member of Schuler formation; Phillips Petroleum Company's Claudia No. 1, Dorcheat pool, Columbia County, Arkansas; core 8,001–2 feet; × nicols; ×25.

FIG. 6.—Thin section of gray, arenaceous, conglomeratic limestone, containing angular to subangular quartz and rounded pebbles and coarse grains of quartzite; part of quartzite pebble is shown in lower half of picture; Shongaloo member of Schuler formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; core 6,468–85 feet; × nicols; ×25.

FIG. 7.—Thin section of gray, fine- to medium-grained, angular to subangular, calcareous, slightly feldspathic sandstone; calcite occurs as finely crystalline cementing material; Shongaloo member of Schuler formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; core 6,367–82 feet; × nicols; ×25.

FIG. 8.—Thin section of part of quartzite in arenaceous, calcareous sediments of Shongaloo member, Schuler formation; saw-tooth contacts of quartz grains are shown; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; core 6,367–82 feet; × nicols; ×25.

FIG. 9.—Thin section of part of pebble of gray novaculite on left, and of part of enclosing arenaceous red shale on right; Shongaloo member of Schuler formation; White and Vaughan's Jackson No. 1, Franklin County, Texas; core 7,903–20 feet; × nicols; ×25.

FIG. 10.—Thin section of greenish gray, arenaceous shale containing spherulites of siderite; spherulites have large dense core and one thick radially crystalline peripheral zone; Dorcheat member of Schuler formation; Phillips Petroleum Company's Claudia No. 1, Dorcheat pool, Columbia County, Arkansas; core 6,821–31 feet; plain light; ×25.

FIG. 11.—Thin section of greenish gray, arenaceous shale containing a botryoidal cluster of tiny spherulites of siderite and single, zoned spherulites; Dorcheat member of Schuler formation; Ohio Oil Company's Taylor No. 15, Haynesville pool, Claiborne Parish, Louisiana; core 7,641–61 feet; plain light; ×25.

FIG. 12.—Thin section of greenish gray, arenaceous shale containing single- and multiple-zoned spherulites of siderite; Dorcheat member of Schuler formation; Ohio Oil Company's Taylor No. 15, Claiborne Parish, Louisiana; core 7,816–36 feet; plain light; ×25.

NOTE: As an eyepiece without crosshairs was not available when the photographs were made, these appear in all of the pictures.

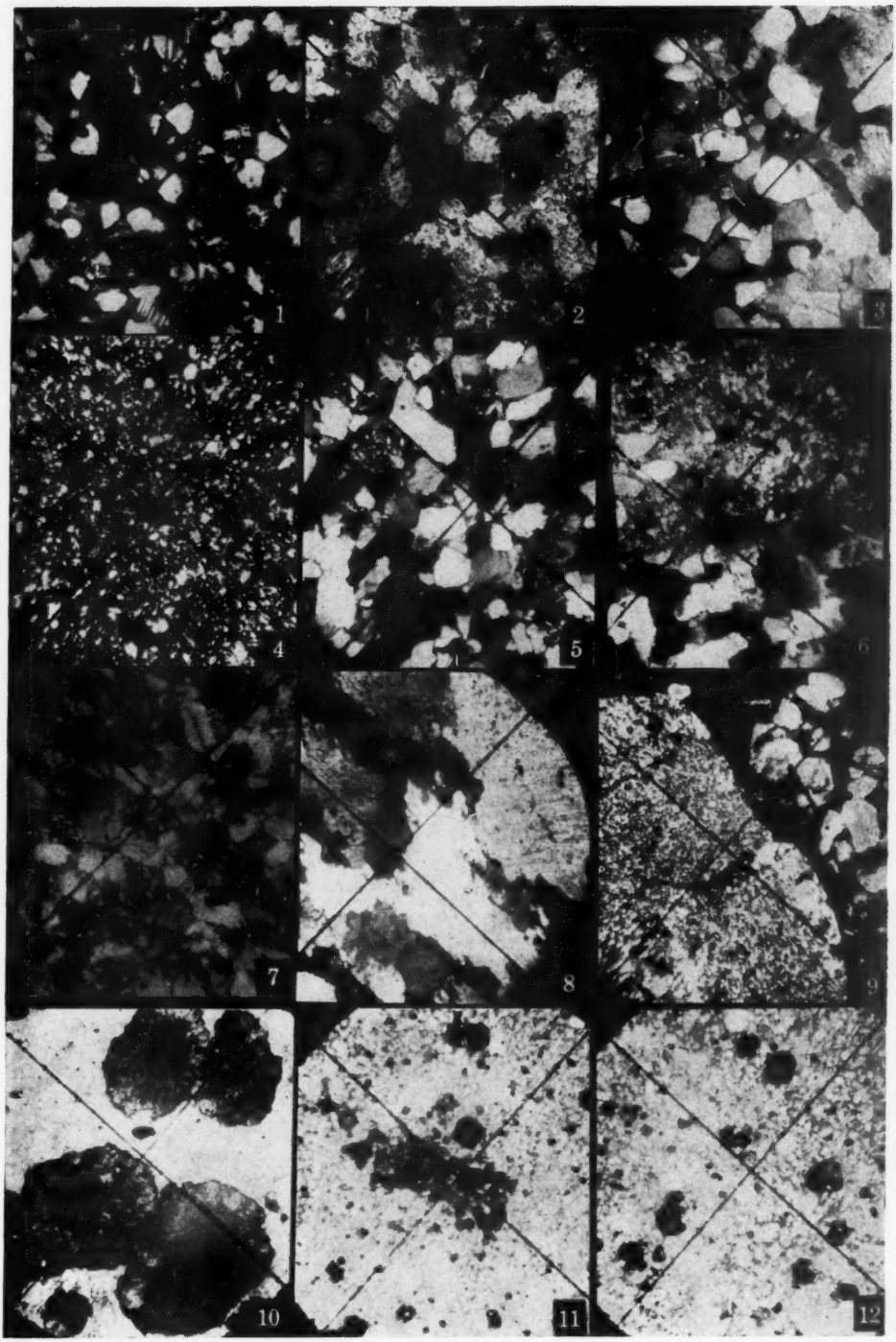


PLATE I

PLATE 2.—Thin sections of Upper Jurassic sedimentary rocks in southern Arkansas, northern Louisiana, and northeastern Texas.

FIGS. 1, 5.—Thin sections of dark gray to black shale containing abundant resinous organic matter; Bossier formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; core 7,654–64 feet; plain light; ×25.

FIG. 2.—Thin section of dark gray shale containing more sparsely disseminated organic matter than the preceding; Shongaloo member of Schuler formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; core 6,382–97 feet; plain light; ×30.

FIG. 3.—Thin section of dark greenish gray arenaceous shale, considerably indurated, containing chloritized areas (gray area in middle of picture), and abundant tiny crystals of pyrite (black pinpoints); Shongaloo member of Schuler formation, above anhydrite and rock salt that probably represents piercement dome; Shell Oil Company's Goldsmith No. 1, Hawkins pool, Wood County, Texas; cutting sample 11,220–30 feet; plain light; ×25.

FIG. 4.—Thin section of oyster shell coquina, characteristic of layers in offshore facies of Schuler formation; Shongaloo member of Schuler formation; Ohio Oil Company's Taylor No. 15, Haynesville pool, Claiborne Parish, Louisiana; core 8,460–77 feet; × nicols; ×25.

FIG. 6.—Thin section of light red, crystalline rock salt (colorless area showing cubic cleavage) occurring as small masses in red, partly arenaceous shale; here salt cuts across and intercalates between lamination planes of shale; isolated patch of red clay and strained appearance of shale next to salt suggests that salt partly squeezed its way into red muds while they were still soft; small finger of salt pinches out a few millimeters on right, outside of picture; Buckner formation; Sun Oil Company's Rutledge No. 1, Kaufman County, Texas; core 9,863–73 feet; plain light; ×25.

FIG. 7.—Thin section of dense to finely crystalline anhydrite occurring as thick-bedded layers in Buckner formation; distorted appearance of crystals suggests internal rearrangement during or after consolidation of material; Sun Oil Company's Rutledge No. 1, Kaufman County, Texas; core 9,960–70 feet; × nicols; ×25.

FIG. 8.—Thin section of part of nodular mass of dense anhydrite in red shale, typical of upper part of Buckner formation; Sun Oil Company's Rutledge No. 1, Kaufman County, Texas; core 9,912–22 feet; × nicols; ×25.

FIG. 9.—Thin section of fairly porous, oölitic limestone containing large crystals of dolomite that have partly replaced oölites; outlines of oölites retained in dolomite crystal here illustrated; upper part of Smackover formation; Sinclair-Prairie Oil Company's Shofner No. 1, Chapel Hill pool, Smith County, Texas; core 12,086–90 feet; plain light; ×25.

FIG. 10.—Thin section of porous, oölitic, asphaltic limestone; asphalt (dark material) has corroded edges of oölites, and has partly replaced others; upper part of Smackover formation; Sinclair-Prairie's Shofner No. 1, Smith County, Texas; core 12,086–90 feet; plain light; ×25.

FIGS. 11–17.—Calcareous algae in dense limestone at top of Smackover formation. Sinclair-Prairie's Shofner No. 1, Smith County, Texas; core 12,015 feet; plain light; ×25. FIGS. 11–14, 16, 17, *Diploporal* sp., cross sections and longitudinal sections. FIG. 15, chance tangential sections of apparently subspherical algal? bodies.

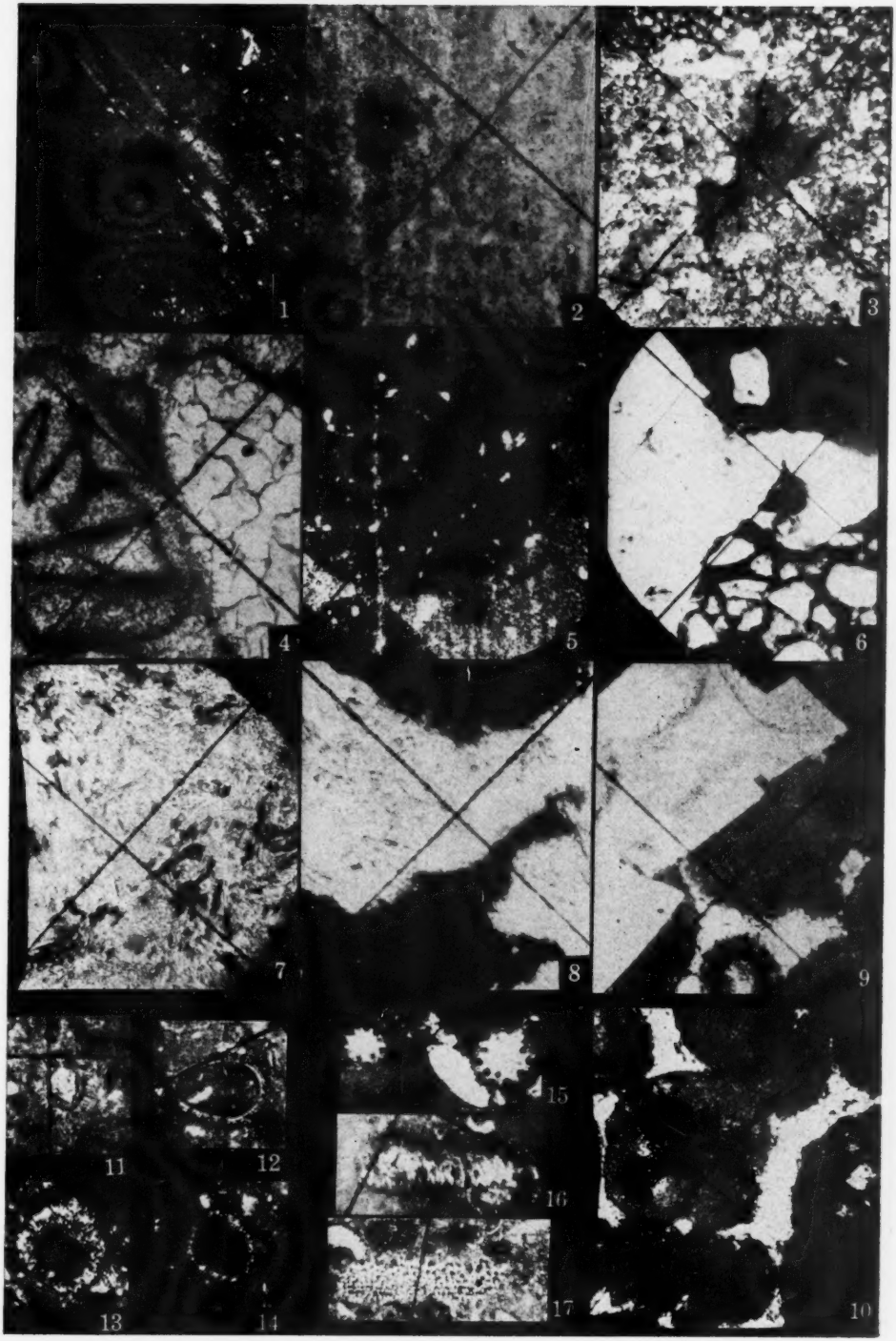


PLATE 2

PLATE 3.—Ostracodes in Schuler and Bossier formations in northern Gulf region. Several have already been described (Swain, 1946; Swartz and Swain, 1946); remainder will be systematically described later. *Ilyocypris* and *Cypridea* occur in nearshore facies of Schuler formation and indicate brackish- or fresh-water environment; other Schuler forms occur in its offshore, definitely marine, facies. F. M. Swartz assisted in photography and laboratories of Pennsylvania State College were used in part of work.

FIG. 1.—*Cytherella* sp., left side of complete shell; Dorcheat member of Schuler formation; Phillips Petroleum Company's Kendrick No. 1; Bossier Parish, Louisiana; cutting sample 5,280–90 feet; ×33.

FIGS. 2, 3.—*Cytherella* sp.; left valve views of two shells; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 4,900–19 feet; ×36.

FIG. 4.—*Cytherelloidea* sp.; left valve view of complete shell; Dorcheat member of Schuler formation; Humble Oil and Refining Company's Bliss and Weatherby No. 30, Bossier Parish, Louisiana; core 5,260–61 feet; ×36.

FIG. 5.—*Paracypris* sp.; right side of shell that is slightly imperfect terminally; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 5,291–5,311 feet; ×36.

FIG. 6.—*Cytheridea* sp.; right side of complete shell; Dorcheat member of Schuler formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; cutting sample 5,300–10 feet; ×33.

FIGS. 7, 8.—*Bythocypris* sp.; right valve views of two complete shells; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 4,937–55 feet; ×36.

FIGS. 9, 10.—*Cytheridea?* sp.; right valve views of two shells that are much more convex than Fig. 6; Dorcheat member of Schuler formation. FIG. 9, Morgan's Smith No. 2, Bossier Parish, Louisiana; core 5,291–5,311 feet; ×36. FIG. 10, Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; cutting sample 5,280–90 feet; ×33.

FIGS. 11–13.—*Eocytheropteron* sp.; left sides and ventral views of three complete shells; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 5,245–46 feet; ×36.

FIGS. 14, 15.—*Schuleridea acuminata* Swartz and Swain. Fig. 14, right side of holotype; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 4,937–55 feet; ×55. Fig. 15, right side of an immature shell; Phillips Petroleum Company's Kendrick No. 1; cutting sample 6,895–6,900 feet, within Bossier formation; specimen probably has caved from higher level; ×36.

FIG. 16.—*Cytheromorpha* sp.; right side of complete shell; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 5,291–5,311 feet; ×36.

FIG. 17.—*Schuleridea pentagonalis* Swartz and Swain; right side of holotype; Dorcheat member of Schuler formation; Union Producing Company's McDonald No. A-1, Claiborne Parish, Louisiana; cutting sample 8,550–55 feet; ×36.

FIG. 18.—*Paraschuleridea anumbonata* Swartz and Swain; right side of holotype; Shongaloo member of Schuler formation; Union Producing Company's McDonald No. A-1, Claiborne Parish, Louisiana; cutting sample 8,820–25 feet; ×36.

FIG. 19.—*Hutsonia vulgaris* Swain; left side of holotype; Dorcheat member of Schuler formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; cutting sample 5,620–40 feet; ×36.

FIG. 20.—*Hutsonia vulgaris* var. *elongata* Swain; left side of holotype; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 5,063–81 feet; ×36.

FIGS. 21, 22.—*Hutsonia* sp.; two immature shells not definitely referable to described species; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 5,045–63 feet; ×36.

FIG. 23.—*Brachycythere tumidosa* Swartz and Swain; left side of holotype; Dorcheat member of Schuler formation; Union Producing Company's Meadows No. A-1, Clairborne Parish, Louisiana; cutting sample 7,540–50 feet; ×36.

FIG. 24.—*Ilyocypris?* sp.; right side of large complete shell; Dorcheat member of Schuler formation, nearshore facies; Hunt's Mitchiner No. 1, Claiborne Parish, Louisiana; cutting sample 7,575–80 feet; ×30.

FIG. 25.—*Eucythere?* sp.; right side of slightly damaged shell; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 4,937–55 feet; ×36.

FIGS. 26, 27.—*Pterygocythereis?* sp.; ventral and left sides of shell that is incomplete anteriorly; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 4,900–19 feet; ×36.

FIG. 28.—*Loxoconcha?* sp.; left side of a complete shell; Bossier formation; Phillips Petroleum Company's Kendrick No. 1, Bossier Parish, Louisiana; cutting sample 6,830–35 feet; ×36.

FIGS. 29, 30.—*Ilyocypris* sp.; left sides of shells that probably are female and male dimorphs, respectively; Dorcheat member of Schuler formation, nearshore facies; Gulf Oil Company's Rhymes No. 1, Richland Parish, Louisiana; well cuttings 7,769–79 feet and 7,966–76 feet; ×36.

FIG. 31.—*Krithe?* sp.; left side of complete shell; Dorcheat member of Schuler formation; Morgan's Smith No. 2, Bossier Parish, Louisiana; core 4,900–19 feet; ×36.

FIG. 32.—*Cypridea* cf. *wyomingensis* Jones; right side of complete shell; Shongaloo member of Schuler formation, Standard Oil Company's (Louisiana) Zimmerman No. 1, Union County, Arkansas; cutting sample 7,030 feet; ×36.

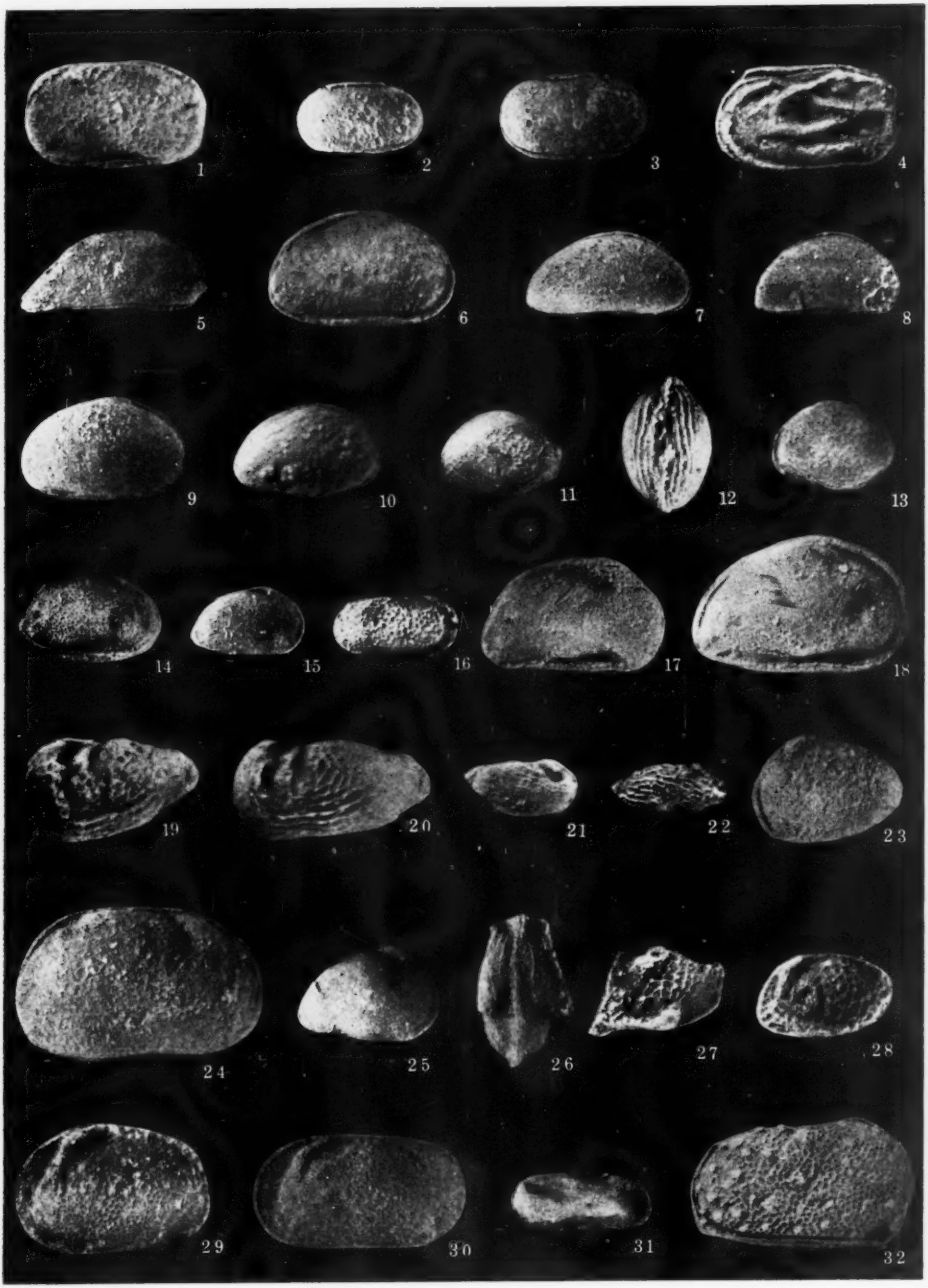

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PLATE 3

the gradual lowering of the Ouachita source and the filling of the basin of Schuler sedimentation. An offlap relationship exists between the Dorcheat and the Shongaloo along the western margin of the basin, at least from Ellis County southward, probably because of the proximity of the Llano source and because of its steeper relief in later Schuler time.

The Shongaloo rests on the Bossier formation in southern Bowie, Marion, Panola, Shelby, and probably in the other East Texas border counties, in southernmost Red River County, and in Franklin, Titus, Morris, eastern Wood, and Smith counties.

The Shell Oil Company's Goldsmith No. 12, Quitman pool, central Wood County, encountered anhydrite and rock salt directly beneath a probably incomplete section of the Shongaloo (Fig. 5). Possible interpretations are: (1) a piercement salt dome; (2) an expanded body of salt in the Buckner formation which contains layers and crystals of salt on the west in Kaufman and Hunt counties; (3) an occurrence, in the Eagle Mills, of salt, not domed, but faulted up against the Shongaloo. Analysis of salt from the Goldsmith well and of salt from the Eagle Mills formation from the Gulf Oil Company's Werner No. 49, Ouachita County, Arkansas, showed only halite. Salt from the Buckner formation in the Rutledge well contains intermixed dolomite. The arenaceous green shale above the capping anhydrite in the Goldsmith well is indurated and apparently chloritized. A salt-dome origin is favored by several company geologists in the area, on the basis of geophysical evidence.

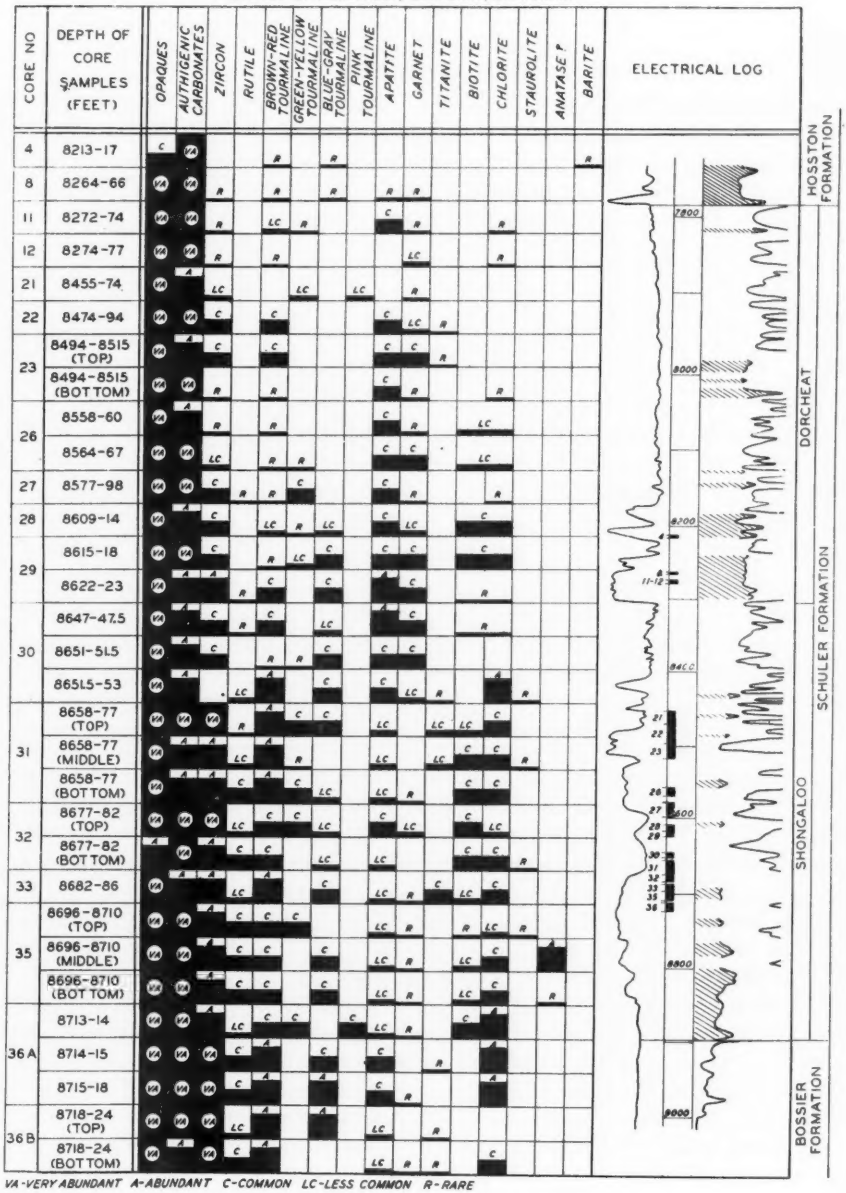
Elsewhere in East Texas the Shongaloo rests unconformably on the Buckner formation except along the western margin of the basin, where it locally oversteps the Buckner and lies on metamorphosed Paleozoic rocks.

Petrographic examination of the Shongaloo sediments of southern Arkansas, northern Louisiana, and the northern part of the East Texas basin shows that the source rock was mostly granitic, but abundant leucoxene at several horizons in northern Louisiana suggests a more mafic source rock. The quartz of the sandstones is mostly angular to subangular, commonly shows strain shadows, secondary growth, and numerous inclusions. In Arkansas and Louisiana the pebbles in the conglomeratic layers are mostly fine- and coarse-grained quartzites that exhibit marked saw-toothed contacts of the grains. Along the northern margin of the East Texas basin, the pebbles in the Shongaloo are predominantly white and gray chert, but quartz pebbles also occur. Along the western margin of the basin, conglomerates of the Shongaloo include pebbles of chert, quartzite, and mica schist, commonly stained by ferric oxide. Grains of fine-grained, gray, siliceous, novaculitic material have the appearance of metamorphosed siltstone in thin section and produce a salt-and-pepper appearance in some sandstone layers. Most of the sandstones are slightly feldspathic and contain from a trace to several per cent of mostly cloudy and altered, but partly fresh, angular to subangular orthoclase, microcline, and sodic plagioclase. The common primary accessory minerals are zircon, apatite, tourmaline, and garnet. Leucoxene is abundant in some places.

TABLE II

HEAVY MINERALS FROM PART OF SCHULER FORMATION (UNION PROD. CO., BROWNFIELD NO. 2, SUGAR CREEK POOL, CLAIBORNE PSH., LA.)

PREPARED BY L.E. MONLEY, L.M. PERRY, & F.M. SWAIN



VA-VERY ABUNDANT A-ABUNDANT C-COMMON LC-LESS COMMON R-RARE

TABLE III

SPECIFIC GRAVITY OF CORE SAMPLES OF JURASSIC ROCKS IN ARKANSAS, LOUISIANA, AND TEXAS

Operator	Lease	Location	Formation	Depth (Feet)	Description	Specific Gravity
1. Phillips Pet. Co.	Claudia No. 1	Union Co., Ark.	Schuler	6,821–31	Varicolored shale with spherulitic siderite	2.77
2. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Schuler	6,367–82	Fine-grained, gray, fossiliferous sandstone	2.52
3. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Schuler	6,382–90	Very fine-grained, gray, calcareous, silty sandstone	2.38
4. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Schuler	6,390–95	Fine-grained, gray, fossiliferous sandstone	2.49
5. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Schuler	6,458–68	Very argillaceous, gray, conglomeratic tight sandstone	2.57
6. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Schuler	6,477–78	Fine-grained, gray, calcareous sandstone	2.58
7. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Schuler	6,479–81	Fine-grained, gray, calcareous sandstone	2.62
8. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Schuler	6,485–99	Fine-grained, gray, porous sandstone	2.38
9. Phillips Pet. Co.	Kendrick No. 1	Bossier Psh., La.	Bossier	7,654–64	Dark-gray to black fissile shale	2.60
10. Furlong	Clark No. 1	Morehouse Psh., La.	Schuler	5,524–26	Red, very sandy, hematitic shale	2.65
11. White-Vaughan	Jackson No. 1	Franklin Co., Tex.	Schuler	7,903–18	Red, very sandy, hematitic shale	2.54
12. White-Vaughan	Jackson No. 1	Franklin Co., Tex.	Schuler	7,918–20	Greenish gray, argillaceous dolomite	2.78
13. Sun Oil Co.	Rutledge No. 1	Kaufman Co., Tex.	Buckner	9,863–73	Red sandy shale and halite	2.65
14. Sun Oil Co.	Rutledge No. 1	Kaufman Co., Tex.	Buckner	9,960–70	Dense gray dolomite with pockets of halite	2.756
15. Sinclair Oil Co.	Shofner No. 1	Smith Co., Tex.	Smackover	12,086–90	Dense, partly oölitic, nonporous limestone	2.70

The tourmaline exhibits various colors and shapes, and detailed study of it together with the other heavy minerals would probably reveal zonal relationships (Table II). Pyrite is locally abundant as irregular aggregates of secondary origin in the offshore sediments of the Shongaloo. Chlorite is common at some levels.

DORCHEAT MEMBER

Throughout the East Texas basin the Dorcheat member of the Schuler formation consists of nearshore, interbedded, cherty conglomerates, white sandstones, light to medium gray and varicolored shales or mudstones, that pass downdip into dark gray fossiliferous shales, sandstones, and limestones. The thickness varies from a feather edge at the margins of the basin to 1,500 feet in The Texas Company's White No. 1, central Freestone County. The average thickness is 1,000 feet. The member has been recognized in wells from Robertson County, Texas, east of the Llano uplift, to east-central Mississippi. The details of its stratigraphy in Texas are shown in Figures 3–7.

In the East Texas border counties, the Dorcheat member is much the same as in adjacent Arkansas and Louisiana. Figure 3, in which sample data are incomplete, shows its inferred correlation from northern Bowie County to central Shelby County. The change from non-marine or brackish-water to offshore marine sediments probably occurs in southern Marion and northern Harrison counties, but this area has not yet been drilled. The change involves southward passage of varicolored pastel shales and sandstones to dark gray fossiliferous shales, sandstones, and limestones. In southwestern Arkansas, the two members of the

Schuler formation became marine in nearly the same area, although in some places the Shongaloo member is marine farther updip than the Dorcheat member (Swain, 1944, pp. 586–88). In the East Texas basin, the Shongaloo generally is marine much farther updip than the Dorcheat (Fig. 9). The zone of principal color change of both members in southwestern Arkansas is in central Miller County. In adjacent Texas the zone of change in the Dorcheat member swings sharply southwest, whereas that in the Shongaloo continues nearly due west.

The sequence in the Magnolia and Tide Water's Hall Estate No. 1, Marion County, Texas, illustrates the non-marine character of the Dorcheat in an area many miles south of its facies change in Arkansas (information supplied by Shell Oil Company).

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
DORCHEAT MEMBER		
Interbedded green, waxy shale, carbonaceous shale in thin layers, and white, fine- to medium-grained, partly asphaltic sandstone	9,160–9,220	60
Interbedded green and red waxy shale	9,250	30
Light gray and white, fine- and medium-grained, calcareous, slightly porous to tight, slightly asphaltic and lignitic sandstone	9,370	120
Varicolored shale	9,470	100
White, fine- to medium-grained porous sandstone, and varicolored green and reddish shale	10,100	630
SHONGALOO MEMBER		
Light, brownish gray, crystalline, fossiliferous limestone, and dark gray partly sandy shale.....Total depth	10,244	

Study of thin sections and heavy-mineral separations from core samples of the Dorcheat revealed its similarity to the Shongaloo member in detrital mineral composition. In northeastern Texas, the shales of the Dorcheat are more ferruginous, darker, and more sandy than in Arkansas. The spherulitic siderite, characteristic of the member in Arkansas, is almost absent in Texas.

STRATIGRAPHIC SIGNIFICANCE OF SPHERULITIC SIDERITE

These tiny pellets (Swain, 1944, pp. 604–05) have been called ankerite by some geologists in the region, but according to X-ray analysis by Thomas F. Bates of Pennsylvania State College, they have the crystal lattice of siderite, and the Dorcheat material, when placed in methylene iodide solution (specific gravity 3), was found to be heavier than ankerite.

The formation of spherulitic siderite in the Coal Measures of England has been described by Deans (1934) and Spencer (1925). This type of siderite should not be confused with the massive, nodular "clay ironstone" which occurs in both marine and non-marine sediments of many geological ages. For example, in the Gulf region, massive siderite is found in the Shongaloo member of the Schuler formation, in the Hosston, Paluxy, Woodbine, Eagle Ford, and Navarro formations of the Cretaceous, and in the Midway, Wilcox, and Claiborne groups of the Tertiary.

Spherulitic siderite occurs in clays and sandstones of non-marine or possibly

brackish-water origin that are widely distributed in the geologic column. In all occurrences, so far as known, it appears to be authigenic material formed by residual weathering. In the Coal Measures of England the spherulitic siderite occurs as subspherical pellets averaging less than one millimeter in diameter, and having a dense, structureless inner zone of siderite surrounded by one or more zones of radially crystalline siderite. It occurs only in the basal parts of underclay, as closely packed layers and pockets, or sparsely disseminated. The matrix is commonly clay or sandy clay, less commonly sandstone. Chamosite (an earthy hydrous iron aluminum silicate of the chlorite family that may simulate glauconite) occurs here and there with the siderite.

The iron was precipitated contemporaneously with the sediment, having been transported by streams to the swampy basin of deposition as colloidally suspended ferric oxide hydrosol ($Fe_2O_3 \cdot H_2O$). The environment of deposition was brackish or fresh, stagnant, lagoonal water, rich in plant life. Biochemical reactions resulted in reduction of the ferric oxide, and, in the presence of carbonate ions, ferrous carbonate or bicarbonate formed. The probably warm lagoonal water would favor a concentration of the carbonate ion and the precipitation of ferrous carbonate. The form taken by the precipitated ferrous carbonate is uncertain, but was temporary.

After the lagoons silted up, a long period of subaerial leaching and oxidizing by ground waters formed an underclay. The disseminated ferrous carbonate near the surface was taken into solution as ferric oxide hydrosol, carried downward to the zone of stagnation, reduced and reprecipitated as ferrous carbonate. It seems plausible that much of the enclosing clay was in the colloidal state, so favorable conditions for the precipitation of nodular siderite would be provided.

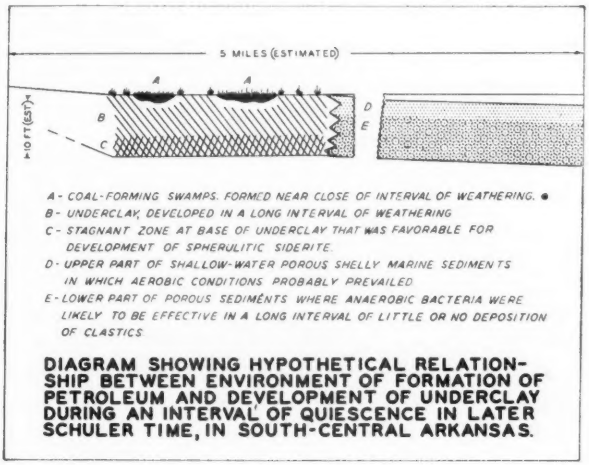
According to Morse, Warren, and Donnay (1932), artificial spherulites of siderite can be prepared by diffusing sodium carbonate into a gelatine gel containing a small amount of ferrous chloride. The present writer found a watery gel more satisfactory than a stiff one, which had much flocculation of the ferrous chloride. Good spherulites formed in the watery gel, but they were too incoherent to be removed for examination under the microscope.

In the natural environment the initial precipitation probably would be as a gel, forming the dense inner cores of the spherulites. Additional slow and variable deposition around the nucleus would take the form of radial crystals, commonly in zoned arrangement. Climatic variations during the long time required to produce underclay would cause fluctuation in the water table and produce irregular vertical distribution of the spherulitic siderite.

An important feature of Deans' discussion is his emphasis on the cyclical (cyclothemic) nature of the beds containing the spherulitic siderite. The sequence in such a cyclothem is (1) non-marine sandstone, (2) fine sediments with spherulitic siderite, (3) underclay, (4) coal, (5) estuarine blue shale, (6) marine blue shale and, (7) mixed marine and brackish blue shale. The period of quiescence occurs midway in the cyclothem.

The Dorcheat member as developed in southern Arkansas and northernmost

Louisiana is believed to provide a close analogy to the conditions presented by Deans. The most obvious difference is the lack of close interfingering of marine and non-marine strata in the Dorcheat throughout most of the area where the siderite occurs. This is readily explained by the relative stability of the Dorcheat shoreline (Swain, 1944, pp. 586–89, 596), as compared with the striking and complex fluctuations of the Upper Carboniferous coal-basin shorelines in England and the interior United States. A succession of uplifts in the area of erosion, fol-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A - COAL-FORMING SWAMPS, FORMED NEAR CLOSE OF INTERVAL OF WEATHERING.
B - UNDERCLAY, DEVELOPED IN A LONG INTERVAL OF WEATHERING
C - STAGNANT ZONE AT BASE OF UNDERCLAY THAT WAS FAVORABLE FOR DEVELOPMENT OF SPHERULITIC SIDERITE.
D - UPPER PART OF SHALLOW-WATER POROUS SHELLY MARINE SEDIMENTS IN WHICH AEROBIC CONDITIONS PROBABLY PREVAILED.
E - LOWER PART OF POROUS SEDIMENTS WHERE ANAEROBIC BACTERIA WERE LIKELY TO BE EFFECTIVE IN A LONG INTERVAL OF LITTLE OR NO DEPOSITION OF CLASTICS.
DIAGRAM SHOWING HYPOTHETICAL RELATIONSHIP BETWEEN ENVIRONMENT OF FORMATION OF PETROLEUM AND DEVELOPMENT OF UNDERCLAY DURING AN INTERVAL OF QUIESCENCE IN LATER SCHULER TIME, IN SOUTH-CENTRAL ARKANSAS.

FIG. 10

lowed by base-leveling and long periods of quiescence with development of leached and oxidized clays, seems a plausible explanation of the occurrence of spherulitic siderite at many horizons in the Dorcheat. It is significant that the lower part of the member in Arkansas contains fewer zones of siderite than the upper part, suggesting fewer early periods of quiescence.

The lack of spherulitic siderite in the nearshore facies of the Dorcheat member in the East Texas basin suggests that sedimentation was more continuous there than in southern Arkansas. The thickness of the member, however, is generally no greater around the northern and northwestern margins of the East Texas basin than in southern Arkansas. It is likely that these parts of the East Texas basin were receiving sediments from an Ouachita Mountain source that had generally lower relief, but in which uplift was either more frequent or more uniform.

The writer believes that a genetic relationship exists between the sideritic zones in the non-marine facies of the Dorcheat and the formation of petroleum in its offshore facies (Fig. 10). Furthermore, an explanation of the lack of success in finding oil in the Dorcheat in East Texas may be in the absence of the spherulitic siderite zones in that region.

REPRESENTATIVE SECTIONS OF SCHULER FORMATION

The following three sections illustrate the essentially non-marine character of the Dorcheat member and the marine nature of the Shongaloo member in the north-central part of the East Texas basin.

SUMMARIZED LOG OF SCHULER FORMATION

Sinclair-Prairie Oil Company's D. D. Shofner No. 1, W. Dickerson Survey, Chapel Hill field, Smith County, Texas; derrick-floor elevation 470 feet; total depth 12,481 feet in Eagle Mills formation.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
DORCHEAT MEMBER		
Shale, varicolored and dark gray, waxy texture; interbedded with fine-grained, white and reddish sandstone	9,770–9,865	95
Sandstone, white, fine-grained, angular, partly porous, partly calcareous; thin layers of gray and varicolored shale	9,980	115
Shale, varicolored, finely sandy; thin layers of reddish sand	10,102	122
Sandstone, white, fine-grained, angular, porous, partly silty	10,138	36
Shale, varicolored, but darker than above, greenish gray at base	10,198	50
Sandstone, reddish and ferruginous at top, white below, fine- to coarse-grained, angular, partly porous; varicolored shale	10,325	127
Shale, varicolored, partly sandy	10,420	95
Sandstone, white, fine- to coarse-grained, angular to subrounded, partly porous; interbedded varicolored shale with reddish sand streaks	10,610	190
Shale, varicolored, with sand streaks	10,640	30
Sandstone, white, fine-grained, porous to silty and tight; interbedded varicolored shale	10,765	125
SHONGALOO MEMBER		
Shale, dark gray, fissile, with sand streaks	10,775	10
Limestone, light gray, sandy	10,785	10
Sandstone, white, fine-grained, porous to tight and silty; brown oil stain 10,790–800 feet; and interbedded gray shale	10,820	35
Sandstone, white, fine- to coarse-grained, partly porous, conglomeratic at base	10,870	50
Limestone, gray, argillaceous, dense to finely crystalline; interbedded dark gray shale; oysters, echinoid spines	10,995	125
Sandstone, white, fine-grained, calcareous, fossiliferous, partly porous; interbedded gray fossiliferous limestone, dark gray shale; asphaltic material and dead-oil stain at several horizons below 11,140 feet; anhydrite streaks 11,220–30	11,270	275

The basal part of the Hosston formation, overlying the Schuler, is not conglomeratic in this well and consists of fine-grained white sandstones and red, green, and gray shales. The Bossier formation, beneath the Schuler, contains sandstone and limestone layers in its upper part.

SUMMARIZED LOG OF SCHULER FORMATION

Humble Oil and Refining Company's H.N. Wright No. 1, Samuel Story Survey, Morris County, Texas; drive-bushing elevation 338 feet; total depth 11,814 feet in Smackover formation.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
DORCHEAT MEMBER		
Sandstone, white, fine-grained, partly porous; interbedded varicolored pastel shale	8,943–97	54
Shale, varicolored, sandy	9,050	53
Sandstone, white, very fine- to fine-grained, subangular, silty, partly porous	9,095	45
Shale, darkly varicolored, partly sandy	9,130	35

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
No record of samples, cored greenish gray, shaly sandstone and siltstone 9,148–53 feet, and dark red to greenish gray, sandy shale and siltstone 9,278–89 feet	9,292	162
Shale, varicolored, pastel; and white, fine-grained, angular, porous sandstone	9,350	58
No record of samples	9,395	45
Sandstone, white, fine- to medium-grained porous, partly silty, with dark chert grains (cored)	9,411	16
No record of samples	9,445	34
Shale, varicolored, interbedded with darker layers; and white, fine-grained sandstone	9,640	195
SHONGALOO MEMBER		
Limestone, dark gray, coquinoid; interbedded dark gray fossiliferous shale; abundant oyster shells	9,718	78
Shale, dark-gray, fossiliferous, and red, silty, non-fossiliferous; interbedded with white, fine-grained sandstone; *Ilyocypris* sp. 9,787–9,802 feet	9,870	152
Shale, dark gray, fissile; interbedded with gray, oyster-bearing, partly oölitic limestone, and less white, fine-grained, calcareous sandstone; *Hutsonia?* sp. 9,998–10,014 feet, *Metacypris?* sp., *Schuleridea?* sp. 10,158–166 feet	10,270	400
Shale, greenish gray and brick-red, with nodules of white anhydrite	10,360	90
Sandstone, light gray and white, fine-grained at top, conglomeratic at base, calcareous, oyster-bearing slightly glauconitic; interbedded gray, fossiliferous limestone containing disseminated pebbles; pebbles consist of rounded quartz and dark gray chert	10,455	95

The lower 200 feet of the Hosston formation in this well consists of fine- and coarse-grained, white and reddish sandstone, and red shale. Conglomeratic layers containing varicolored ferruginous chert and quartz pebbles occur above 8,750 feet. Here, as in other wells in the East Texas area, the lowermost sandstones of the Hosston are finer-grained than in the middle part, suggesting that the uplift which produced the Hosston sediments in some places did not reach its maximum until middle Hosston time. The Schuler formation in the Wright well is underlain by 200 feet of fine- to coarse-grained sandstones that are reddish in the lower part, and are interbedded with gray, green, and red shales. This interval is thought to represent the nearshore facies of the Bossier formation, here resting on shale, anhydrite, and dolomite of the Buckner. The few ostracodes found in the Shongaloo member of the Schuler are too poorly preserved to permit certain identification. The form questionably referred to *Metacypris* Brady is the only one of its kind seen by the writer in the Schuler formation. It bears a median sulcus, a well defined marginal rim, and a straight hinge, all of which are indicative of the late Paleozoic genus, *Hollina* Ulrich and Bassler. The form questionably referred to *Hutsonia* Swain appears to be related to another upper Paleozoic genus, *Hollinella* Coryell.

SUMMARIZED LOG OF SCHULER FORMATION

Humble Oil and Refining Company's J. F. Hague No. 1, J. P. Riddle Survey, Franklin County, Texas; derrick-floor elevation 422 feet, total depth 11,516 feet in Smackover formation; sample information supplied by Magnolia Petroleum Company.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
DORCHEAT MEMBER		
Shale, brown and greenish gray, waxy	8,650–65	15
Sandstone, white, fine-grained, fairly porous; interbedded varicolored shale	8,800	135

Lithologic Character	Depth (Feet)	Thickness (Feet)
Shale, gray and brittle at top, varicolored below; interbedded with thin layers of sandstone	8,890	90
Sandstone, white, very fine-grained, ashy	8,935	45
Shale, varicolored	9,015	80
Sandstone, white, medium-grained, porous	9,055	40
Shale, varicolored	9,100	45
Sandstone, white, fine- to medium-grained, in thick units; interbedded varicolored and red shale containing streaks of reddish sandstone	9,540	440
SHONGALOO MEMBER		
Shale, green, gray, and red, interbedded	9,650	110
Limestone, brown, finely crystalline	9,700	50
Shale, gray and greenish gray, interbedded, partly calcareous and with thin layers of gray limestone	9,790	90
Limestone, gray-brown, finely crystalline; interbedded with dark gray shale and thin layers of white sandstone	9,910	120
Shale, dark gray and red, interbedded, containing layers of white and reddish fine-grained sandstone, and nodular anhydrite at base	10,090	180
Limestone, gray, finely crystalline	10,125	35
Shale, dark gray and red, interbedded	10,180	55
Limestone, gray, partly oölitic, sandy at base; interbedded dark gray shale, and gray, fine-grained, calcareous sandstone	10,310	130
BOSSIER FORMATION OR LOWER PART OF SHONGALOO MEMBER		
Limestone, gray, finely crystalline, partly oölitic; with interbedded gray shale, and white, fine-grained, calcareous sandstone	10,620	310

The basal part of the Hosston formation in this well is conglomeratic, chloritic sandstone. The interval from 10,310 to 10,620 feet is not appreciably different in lithologic character from the overlying limestone unit of the Shongaloo member, except that the latter is more sandy. The interval is here placed tentatively in the nearshore facies of the Bossier formation, because it is in other wells at the same latitude, and because a thin remnant of it occurs updip in White and Vaughan's Jackson No. 1, northeastern Franklin County.

There are several problems of correlation in the southwestern part of the East Texas basin. Only redbeds and conglomerates of the Shongaloo member represent the Schuler formation in Farrell's Gilliam No. 1, western Limestone County. A short distance downdip, in the Nu-Enamel Oil Company's Bessie Erskine No. 1, southern Limestone County, and H. C. Cockburn and Zephyr Oil Company's N. D. Buie No. 1, eastern Falls County, the Dorcheat member is present and the Shongaloo contains marine layers throughout. The Falls County area received little coarse clastic material throughout Schuler time, whereas central Limestone County, a short distance north, was supplied with abundant gravel in Shongaloo time. A little downdip from the Erskine well in the Stanolind Oil Company's Tennie Norris No. 1, Limestone County, the Dorcheat member is not appreciably thicker, and contains marine units in its upper part, whereas the Shongaloo member is marine in its upper part, and consists of redbeds and conglomerates below. On the east, in The Texas Company's White No. 1, central Freestone County, the Dorcheat is 1,500 feet thick, three times its thickness in the Norris and Erskine wells, and is almost wholly non-marine varicolored shale and white sand-

stone. The Shongaloo member there consists mostly of dark gray, calcareous, non-fossiliferous shale, and impure limestone that probably formed in relatively deep water, but at its base contains layers of shallow-water oölitic limestone with quartz pebbles. The lower part of the Hosston formation in the White well consists of only fine-grained sandstones, whereas farther updip thick basal conglomerates occur. The evidence suggests that in central Freestone County as well as in other deeper parts of the basin, the Hosston is nearly conformable with and gradational into the Schuler. A similar condition has been observed in north-central Louisiana (Swain, 1944, p. 607). Post-Schuler uplift that affected only the margins of the East Texas basin apparently resulted in the removal of part of the Dorcheat member. The thickness of material removed can not be determined because the upper part of the interval assigned to this member out in the basin may consist of reworked earlier Dorcheat.

SUMMARIZED LOG OF SCHULER FORMATION

Texas Company's William White No. 1, William King Survey, 3¼ miles west of Fairfield, Freestone County, Texas; derrick-floor elevation 407 feet; total depth 14,334 feet in Eagle Mills? formation. Samples examined by L. M. Perry and F. M. Swain.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
DORCHEAT MEMBER		
Shale, dark greenish gray and red; interbedded white, fine-grained sandstone	9,660–9,935	275
No record of samples	10,055	120
Sandstone, white, fine- to coarse-grained, partly conglomeratic; interbedded greenish gray and reddish shale	10,590	535
Shale, dark gray and greenish gray	10,625	35
Sandstone, white, fine- to coarse-grained, carbonaceous	10,685	60
No record of samples	11,015	330
Sandstone, white, fine- to coarse-grained, containing quartz pebbles; interbedded dark gray shale	11,065	50
Shale, dark gray, fissile, calcareous	11,110	45
Sandstone, white, fine- to coarse-grained, containing quartz pebbles	11,150	40
SHONGALOO MEMBER		
Shale, dark gray, fissile, calcareous, containing several layers of white, fine-grained sandstone, and dense, impure limestone in upper part; fragmentary mollusk remains at several horizons	12,000	850
Limestone, gray, dense to finely crystalline, in part oölitic; interbedded dark gray shale containing well rounded quartz pebbles	12,145	145

The beds underlying the Shongaloo member consist of dense, partly oölitic, argillaceous to sublithographic limestone interbedded with white anhydrite layers, and are here assigned to the Buckner formation. The writer is uncertain of the exact age of the dark shale and underlying oölitic and conglomeratic layers, here called the Shongaloo member, because the entire interval strongly resembles the Bossier formation. The basal conglomerate and the lack of Shongaloo-type sediments at higher levels, as well as the apparent regional relationships outlined above, lead to the assumption that the interval from 11,150–12,145 feet represents a relatively deep-water facies of the Shongaloo that has shallow-water type of sediments at its base and perhaps at its top.

Further evidence of pre-Cretaceous uplift along the western margin of the basin is found in A. G. Hill's Anderson No. 1, northwestern Robertson County. A description of the Jurassic strata penetrated in the well follows.

SUMMARIZED DESCRIPTION OF JURASSIC ROCKS

A. G. Hill's Anderson No. 1, Joseph Webb Survey, Robertson County, Texas; derrick-floor elevation 326 feet; total depth 10,280? feet, in Smackover formation.

Lithologic Character	*Depth (Feet)*	*Thickness (Feet)*
COTTON VALLEY GROUP		
SCHULER FORMATION		
SHONGALOO MEMBER		
Shale, dark gray, greenish gray, and red; interbedded white, fine-grained sandstone	8,690–8,750	60
Sandstone, white and light gray, calcareous, partly porous	8,770	20
Limestone, gray, dense to finely crystalline, partly oölitic, non-porous	8,870	100
Shale, dark gray, hard, carbonaceous, partly sandy	8,910	40
Sandstone, white, fine- to coarse-grained, conglomeratic in upper part, calcareous	8,940	30
Shale, dark gray, hard; interbedded argillaceous sandstone and siltstone	8,980	40
Limestone, grayish brown, silty, fossiliferous and conglomeratic in lower part; interbedded grayish brown, fine-grained, argillaceous sandstone in upper part	9,110	130
Sandstone, white, fine-grained, calcareous, slightly porous; conglomeratic in upper part	9,200	90
Shale, dark gray, hard, containing thin layers of argillaceous, fine-grained sandstone in upper part, and grayish brown, finely crystalline limestone in lower part; *Estheria* sp. 9,290–9,300 feet, *Schuleridea acuminata* Swartz and Swain 9,320–30 feet, 9,340–50 feet, abundant oyster shells	9,420	220
Sandstone, white, fine-grained, with white quartz pebbles, calcareous	9,430	10
Shale, dark gray, hard; thin limestone layers	9,465	35
Sandstone, white, fine-grained, calcareous, with oysters; interbedded gray, sandy limestone in upper part, dark gray shale below, conglomeratic at base	9,560	90
Shale, dark gray, hard; and gray, calcareous, glauconitic siltstone (cored 9,571–81)	9,590	30
Sandstone, white, fine-grained, partly calcareous, glauconitic, fossiliferous	9,640	50
Sandstone, light red, fine- to coarse-grained, conglomeratic; angular to subrounded pebbles consist of quartz and schist, and in part coated with hematite; lower part less conglomeratic	9,920	280
BUCKNER FORMATION		
Shale, red, hard, silty; conglomeratic sandstone in lower part of interval may be caving	9,940	20
BUCKNER OR SMACKOVER FORMATION		
Limestone, red, pink and white, dense, ferruginous	9,950	10
Shale, black, hard, silty; interbedded reddish, sandy limestone	10,000	50
SMACKOVER FORMATION		
Limestone, gray, dense to finely crystalline, partly oölitic; white, chalky and leached at top; interbedded dark gray to black, hard silty shale	10,070	70
Limestone, medium and dark gray, dense; interbedded dark gray, micaceous, calcareous, silty shale	10,230	160
Limestone, brownish gray, dense to finely crystalline, dolomitic. . Total depth	10,270	

The Anderson well is unique in that, according to the writer's interpretation, the Hosston formation rests on a thick, largely marine section of the Shongaloo

member of the Schuler formation. This conclusion is supported by: (1) lack of Dorcheat-type sediments beneath the Hosston; (2) presence of typical Shongaloo sediments directly underneath the Hosston; and (3) evidence in wells on the north that the Shongaloo is present farther updip than the Dorcheat. The lower part of the Hosston formation here consists of conglomeratic sandstone, with much detrital chert, and interbedded red and gray shales. The absence of chert and presence of abundant schist fragments in conglomerates in the lower part of the Shongaloo suggests that their source was in pre-Cambrian metamorphic rocks, as exemplified by the Packsaddle schist, and that it was east of the Central Mineral region where chert-bearing Cambrian and Ordovician deposits crop out. The abundant chert in the lower part of the Hosston formation suggests that its source was partly in the Lower Ordovician Ellenburger group (Sellards *et al.*, 1932, p. 70) and in the upper part of the Wilberns formation (Pedernales dolomite member), Upper Cambrian (Bridge, Barnes, and Cloud, 1947, p. 122). The absence of chert containing fusulines, which the writer has observed in some of the Cenozoic deposits of East Texas, indicates that the Marble Falls limestone or other late Paleozoic sources supplied little sediment to the lower part of the Hosston. A possible inference as to lack of chert in the Shongaloo member of the Schuler is that the Cambrian and Lower Ordovician strata are not present east of their exposures in the Llano region.

CONCLUSION

The nature and distribution of the rocks underlying the Upper Jurassic in the East Texas basin are relatively unknown excepting perhaps to those who have conducted extensive geophysical surveys of the region. Relatively undisturbed early Paleozoic rocks, east and south of the supposed southern margin of the Appalachian landmass, have been found in several wells in Florida, Georgia, Alabama, and Mississippi (Campbell, 1939; Swartz, 1945; Howell and Richards, 1947). There may be similar occurrences farther west in the north-central Louisiana basin and the East Texas basin.

The scant data obtained from wells along the northern and western margins of the East Texas basin suggest that the northern limit of the pre-Cambrian crystalline rocks of Llanoria may trend eastward from Ellis County. North of Henderson, Smith, Gregg, and Harrison counties, the pre-Mesozoic terrane evidently is formed of metamorphosed Paleozoic strata of the Ouachita geosyncline facies.

The southeasterly limit of the early Paleozoic strata on the north flank of Llanoria is unknown. The Standard Oil Company's (Texas) Mitchell No. 1, 2 miles northwest of Sherman, Grayson County, Texas, penetrated undeformed Viola limestone and earlier Ordovician rocks, beneath unmetamorphosed beds of the Pennsylvanian Atoka formation (C. A. Mix, written communication). Fifty miles east, wells in Lamar County encountered quartzites and phyllites of the late Paleozoic Ouachita facies beneath Lower Cretaceous conglomerates (Fig. 5).

The regional evidence suggests that in the northern Gulf region, the most intense interval of uplift of Jurassic time began at or near the end of the Kimmeridgian, continued intermittently until the end of the period, and in early Cretaceous time was strongly renewed. The preceding early Kimmeridgian or late Oxfordian uplift is believed to have been less intense. Imlay (1943, p. 1,526) has discussed the inter-regional relationships of the late Jurassic diastrophic movements. As in the case of the late Mesozoic and early Cenozoic disturbances in Utah (Spieker, 1946, pp. 149–60), it is evident that there were several intervals of uplift in North America during late Jurassic and early Cretaceous time, which were perhaps localized and did not necessarily occur simultaneously throughout the continent.

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VOL. 33, NO. 7 (JULY, 1949), PP. 1251-1259, 5 FIGS.

PHOTOGEOLOGY IN GULF COAST EXPLORATION[1]

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ABSTRACT

The Gulf Coast has long been noted for the absence of surface geology and topographic expression of subsurface structure. However, with application of geomorphology as a basic principle, aerial photographic interpretative techniques have been developed for this province. The deltaic plain of the Mississippi River and adjacent coastal marsh are selected for demonstration; approach to the problem is outlined, and photogeologic criteria are described and illustrated.

In the business of finding oil, geologists in the Gulf Coast have combed the surface, probed the subsurface, and it is the suggestion of the writer that we get up in the air about exploration.

During the past several years, the use of aerial photography in geologic study has been alternately hailed as a new science and condemned as peek-a-booing, but has been introduced in our literature as "photogeology." It is scientific, but it is not new. Photogeology is no more than a change of perspective.

With the development of the airplane and its associated services soon after 1920, aerial mapping was inaugurated and field geologists were quick to recognize the boon of these mosaics in their plane-table mapping. After 1930, however, the full potentialities of stereoscopic study of contact prints were realized and the photogeologist began slowly to evolve.

Since the end of World War II, photogeology has advanced from an experimental gadget to a successfully applied exploratory tool. During 1947, more than 110,000 square miles in the Rocky Mountain region were covered photogeologically. As interest in the method increases, it is being realized that this type of interpretation is not limited to those physiographic provinces of sparse vegetation and bold outcrop pattern, and photogeologic programs are currently in progress in many varied sections of the United States, including the Gulf Coast.

The use of aerial photographs in the Gulf Coast province has been largely restricted to geomorphic study. One of the first published suggestions that photographic interpretation might be applied to Gulf Coast structure was Barton's paper[3] in 1933, in which he described the relation of drainage in South Texas to a surface fracture pattern from a study of aerial photographs. In the same year Clapp, in a discussion following presentation of papers concerning photographic reconnaissance and evaluation of surface evidences of oil at the World Petroleum Congress, said:

Salt domes and fault lines have been mapped with great exactness by the aid of photo-

[1] Read before the Association in regional meeting at Houston, December 3, 1948. Manuscript received, December 23, 1948.

[2] Consulting geologist. The writer is indebted to Edgar Tobin Aerial Surveys for permission to use the photography in Figures 2, 3, and 4.

[3] Donald C. Barton, "Surface Fracture System of South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), pp. 1194–1212.

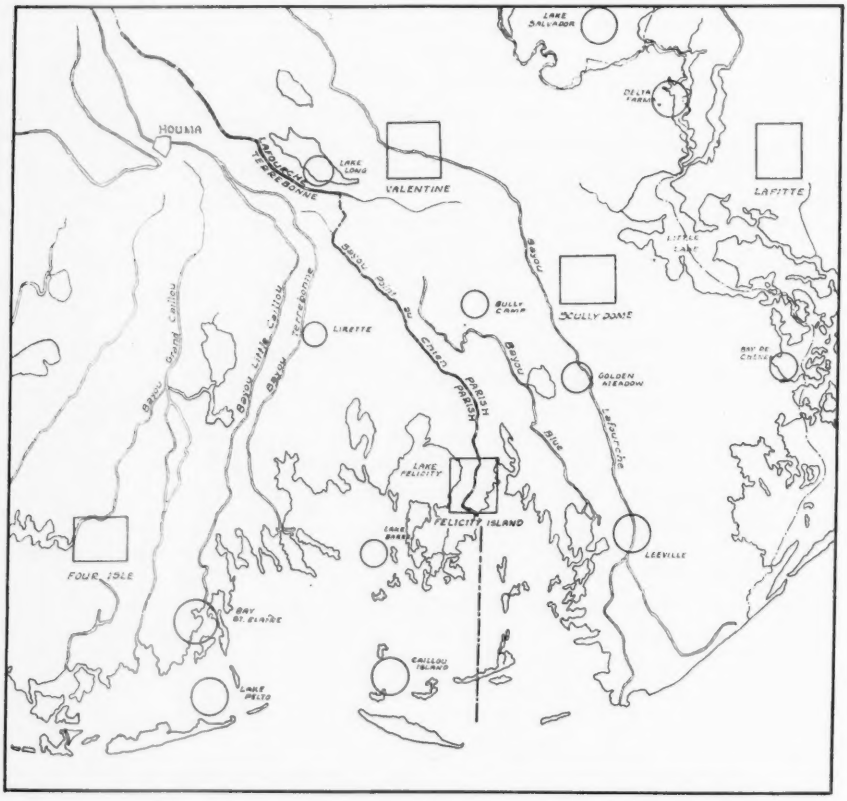

FIG. 1.—Part of Terrebonne and Lafourche parishes, Louisiana, showing location of illustrative areas.

graphs and a number of productive oil-pools are authentically reported to have been discovered by such means.[4]

—again in South Texas.

Rea in his geological-note proposal[5] of the term photogeology cited as an example of the use of aerial photographs, the identification of salt domes in Gulf Coast swamps as anomalous areas from an interpretation of the drainage patterns surrounding them.

[4] Frederick G. Clapp, *Proc. World Petroleum Congress*, Vol. 1 (1933), p. 228.

[5] Henry Carter Rea, "Photogeology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25 (1941), pp. 1796–99.

Fisk[6] attributed some of the topographic features of the alluvial plain to surface expression of structure.

Photogeology in the Gulf Coast refutes the old interdiction that structures in the marsh, in the swamp, and on the prairie have no surface expression. Like all such pronouncements, this followed on the heels of failure. After the initial successes of "mound searching" for oil fields in the lower Gulf Coast, early exploration men dropped the method after drilling numerous erosional and depositional features and discredited it as "creekology." They did not know what they were looking for and, had they known, they could not have recognized it, and neither could we—on the ground. However, rather than exceptional as exhibited by the Five Islands, Starks, Anse la Butte, High Island, Big Hill, Spindletop, and others, surface indication is common in Gulf Coast structures.

For years it has been the plea of broad exploration thinkers to apply an appreciation of geomorphology in refined surface-mapping techniques. A thorough knowledge of geomorphology is the basis for photogeology in the Gulf Coast province. The same criteria are used that were used in 1900 when Spindletop was found—that is why photogeology is not new, but we are looking from an altitude of 20,000 feet—that is the different perspective.

The geomorphic history of the lower Gulf Coast is one of stream deposition, attendant subsidence, and in the northern part, regional tilting and subsequent erosion. Physiographically, the province has been divided into the Pleistocene terraces, deltaic plains, and coastwise plains.[7] Because the deltaic plain of the Mississippi River and adjacent coastal marsh offer the most significant contrasts, they have been selected to demonstrate lines of photogeologic evidence. Unfortunately, as only a few criteria of surface expression are suited to half-tone reproduction, this paper must be limited to examples of these.

The deltaic plains consist of a network of complicated natural-levee systems which rise above the general land level and divide the area into numerous swamp lowlands. Coastward, the natural levees lose height and breadth and finally subside beneath the level of the marsh; the intervening lowlands increase in size at the expense of the shrinking levees and become more marshy toward the coast until the tree growth is entirely replaced by marsh grasses and sedges. A few natural levees associated with major distributary streams remain such prominent features that they persist through the marsh belt and extend into the shallow inshore waters of the gulf. In the deltaic plains, the natural levees are the only positive features in a topographically negative region.

Though the drainage systems appear to be a bewildering fabric of superimposed patterns, close study will reveal that for each of the several sections com-

[6] Harold N. Fisk, "Geological Investigation of the Alluvial Valley of the Lower Mississippi River," *Mississippi River Commission*, War Department, Corps of Engineers, Vicksburg (1944), p. 21.

[7] Fisk, *op. cit.*, Pl. I.

prising the plain, there is a definite and distinct grain.[8] Once established, this grain becomes the photogeologic norm and the interruption of this grain is the first indication of a photogeologic anomaly.

Being the dominant landform, the natural levees in deviation from their normal characteristics exhibit the most obvious photogeologic evidence of structure. One criterion is an abrupt broadening of the levee on one or both sides of a channel in an area of prevalent subsidence. The Valentine dome in Lafourche Parish is an example of broadening on both sides (Fig. 2). Coalescence of Bayou Lafourche natural levees with those of Middle Bayou exaggerate the normal width of the Lafourche levees. Levee broadening over the dome is marked, and, though a drainage project in the western half of the field area has extended the apparent levee width, the true backslope limit is discernible through the cultivated fields. The eastern part of the dome area clearly demonstrates true width over the structure.

During the time Bayou Lafourche was an active distributary of Mississippi waters, its natural levees were several times higher and wider than at present. Subsidence has played the major role in this reduction in size and the local preservation of a conspicuously broader part is credited to the presence of the dome which restricted normal subsidence.

Similar levee broadening is commonly a result of crevassing, high-angle bifurcation, and coalescence (Fig. 2). However, these conditions ordinarily can be readily recognized and differentiated from the abnormal.

More striking examples of diagnostic levee preservation are found in the coastal marshes. At Four Isle in Terrebonne Parish, an isolated levee remnant bearing a growth of small trees rises above the surrounding marsh and nearly over the center of the dome. The location of this fragment of levee is a marked departure from the norm. The last normal occurrence of levees in this section is more than 3 miles upstream along Bayou Grand Caillou, at which point they sink below marsh level.

A more remarkable example is Felicity Island on the Terrebonne-Lafourche parish line (Fig. 3). This "island" is a 2-mile-long natural levee ridge near the distal end of Bayou Pointe au Chien. Several miles of marsh separate this ridge from the normal termination of the bayou levees.

In both of these places it is patent that the natural levees were once continuous across the marsh that now separates the isolated fragments and the present upstream termini. These incongruous occurrences of levee preservation in areas of active subsidence are directly attributed to local subsurface structure.

Another type of surface evidence is commonly found in local peculiarity of stream course. The complex physiographic history of the deltaic plain has given rise to a variety of hydrographic patterns. No section has a single type of stream,

[8] R. J. Russell, "Physiography of the Lower Mississippi Delta," *Louisiana Dept. of Conservation Geol. Bull. 8* (1936), pp. 3–193.

FIG. 2.—Aerial mosaic of Valentine dome area. *a*—Marsh. *b*—Normal Lafourche and Middle Bayou natural levees. b^1—Lafourche natural levees showing coalescence with those of Middle Bayou. *c*—Back swamp. Dashed outline shows approximate location of dome.

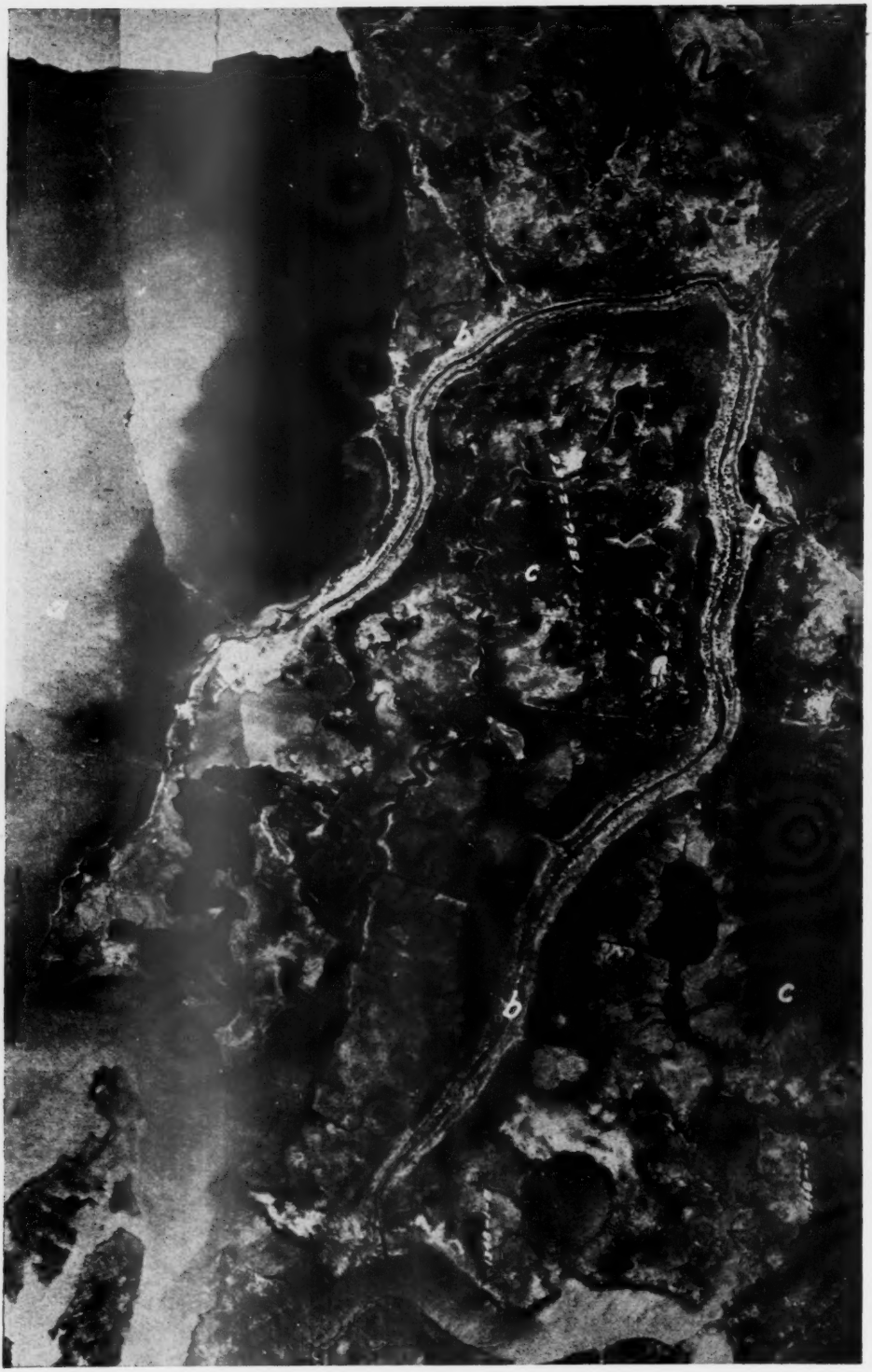

FIG. 3.—Aerial mosaic of Felicity Island area. *a*—Water. *b*—Natural levee ridge. *c*—Marsh.

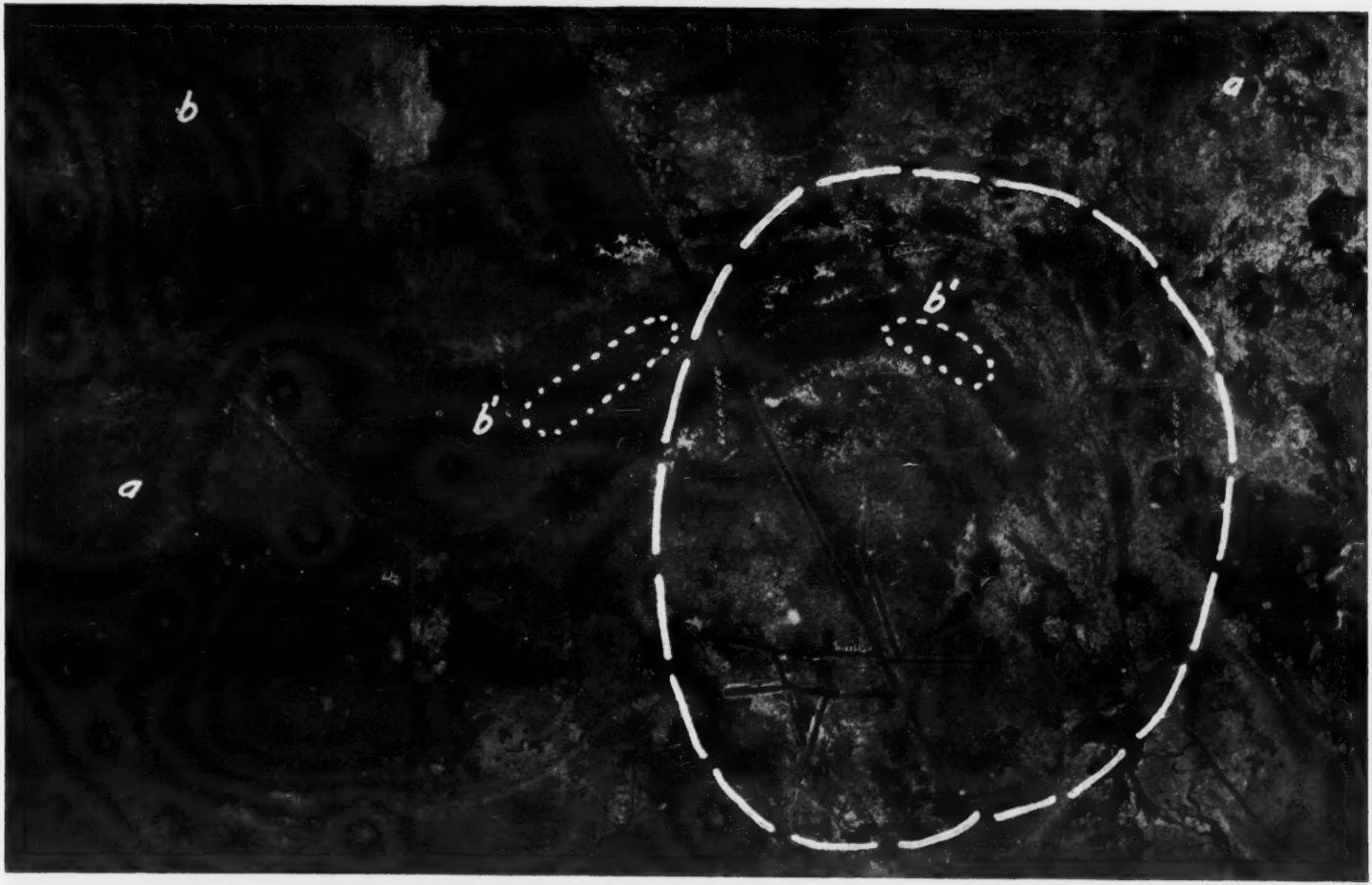

FIG. 4.—Aerial mosaic of Lafitte dome area. *a*—Marsh. *b*—Natural levee. *b*'—Natural levee ridge. Dashed outline shows approximate location of dome.

FIG. 5.—Aerial mosaic of Scully dome area. *a*—Present course of Bayou Lafourche with associated natural levees. *b*—Marsh. *c*—Relic natural levees marking old distributary channels. Dashed outline shows approximate location of dome.

and any stream may change channel pattern several times in its course. Despite this diversity, abrupt change that is locally restricted may be significant.

The behavior of a relic Mississippi River distributary at the point where it crosses the Lafitte field is an example (Fig. 4). The channel for miles both upstream and downstream from this point is simple and straight, but at the Lafitte structure it executes two sharp meander bends. The appearance of these meanders is considered an interruption of grain.

The natural levees are preserved on both sides of the channel and terminate a short way downstream from the field limits. Because these levees are continuous to that point and whatever broadening occurs may be a function of the meanders rather than diagnostic preservation, the occurrence of these levees is not particularly noteworthy. However, the presence of distinct levee-ridge remnants on either side of the channel—the only ones along the entire relic course—is strong supporting evidence.

Another example is related to the Scully dome in Lafourche Parish (Fig. 5). There two relic distributaries of Bayou Lafourche followed simple courses, but suddenly changed to an anastomosing pattern over the dome, then resumed simple courses south of the structure.

Both of these examples may be explained by local flattening of stream gradient, which might have been accomplished by minor uplift, at or near the point of channel pattern change.

There are numerous other evidences of surface expression, for example, change in vegetation, which photographically are expressed by contrasting shades of gray and are not suitable for reproduction.

Generalization is difficult, because of the great variation in physiographic character of the several subdivisions in the Gulf Coast province. Even within a subdivision, surface character may change radically, for example, the marked difference in the Terrebonne-Lafourche marsh and that of Cameron and Vermillion parishes. Where such a change occurs, there is necessarily a corresponding change of norm and photogeologic criteria.

Some of the criteria that have been established for swamp and marsh study are applicable to the terraces and outcrop belt, but their expressions vary with the physiographic history and age of the surface. Other criteria appear to be peculiar to a single physiographic subdivision. The same sort of techniques that are here demonstrated in the deltaic plains can and are being applied throughout the Gulf Coast province.

Many geologists have recognized the adjunctive value of photogeology in exploration, but press of routine work has left little time for extra-professional approach. However, it is worth the time and effort, and it is worth a place in exploratory programs.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1260-1270, 7 FIGS.

STRAND-LINE ACCUMULATION OF PETROLEUM, JIM HOGG COUNTY, TEXAS[1]

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ABSTRACT

Old strand lines furnish a distinct type of petroleum accumulation. The Laredo district of Texas is characterized by strand-line type accumulation. The relationship between strand lines and accumulation of petroleum in Jim Hogg County, Texas, is described. In this area, effective closure is present along strand lines even though structural deformation of producing beds in many fields is secondary and may or may not serve to localize accumulation along strand lines. The methods applied in the Laredo area are applicable to other areas of similar geologic history.

INTRODUCTION

The trend in geologic thinking of petroleum geologists in recent years has been directed more and more toward the fields of stratigraphy and sedimentation, including studies of permeability and porosity of sediments. This trend was brought about by the realization of the importance of these factors in exploration geology as well as in production geology.

A stratigraphic trap has been defined as "one in which variation in the stratigraphy is the chief confining element in the reservoir which traps oil."[3] Oil fields vary in classification from purely stratigraphic to purely structural traps with every variation between. The following classification of closed reservoirs was proposed by W. B. Wilson.[4]

1. Reservoirs closed by local deformation of strata
2. Reservoirs closed by varying porosity
3. Reservoirs closed by combination of folding and varying porosity
4. Reservoirs closed by combination of faulting and varying porosity

A somewhat different subdivision of the second type of closed reservoir is the following.

a. Accumulation due to unconformities
b. Accumulation in shoestring sands
c. Accumulation due to varying porosity in a particular stratum, such as due to solution, dolomitization, or cementation
d. Accumulation related to old strand lines

The East Texas field is a classic example of accumulation due to unconformity —the uplift and truncation of the reservoir rock and its overlap by an impervious layer. The lenticular sands of Kansas, Oklahoma, and Michigan are examples of the shoestring sand type. The West Texas area is characterized by fields which

[1] Written as a Master's degree thesis, University of Colorado, 1947. Read before South Texas Section of A.A.P.G., August 23, 1948. Manuscript received, February 8, 1949.

[2] Geologist, Magnolia Petroleum Company. The writer is indebted to John R. Sandidge, and to W. O. Thompson and others of the geology department of the University of Colorado, for encouragement and advice.

[3] A. I. Levorsen, "Stratigraphic Versus Structural Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 5 (May, 1936), p. 524.

[4] W. B. Wilson, "Classification of Oil and Gas Reservoirs," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), p. 442.

are the result of varying porosities. The Laredo district of Texas is characterized by fields related to old strand lines.

This paper outlines the factors involved in strand-line type accumulation of petroleum. Jim Hogg County in the Laredo district of Texas is used as an area of demonstration.

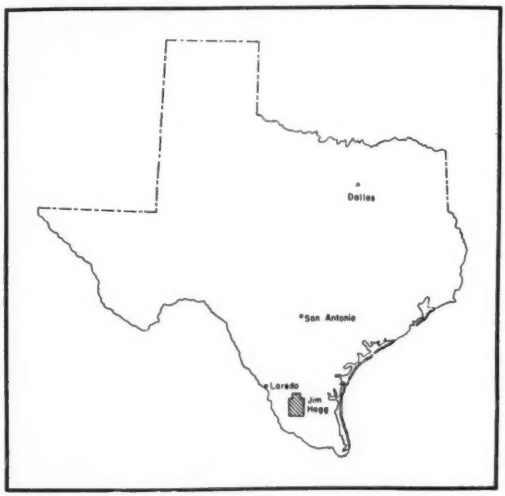


FIG. 1.—Location of area of study.

LOCATION OF AREA OF STUDY

The Laredo district of Texas comprises the shallow producing trend of the Jackson and Yegua formations. It includes Duval, Webb, Jim Hogg, Zapata, and parts of Starr and McMullen counties. Jim Hogg County is in the east-central part of the area.

STRATIGRAPHY

This study is concerned with the Jackson and upper Yegua formations, Eocene in age. Figure 2 shows the generalized section with the microfaunal subdivisions, local sand names, and a type log.

DEPOSITIONAL HISTORY[5]

The sand zones here studied lense out updip and downdip. They are traceable parallel with the strike of the beds throughout the area. The width of these sand

[5] J. M. Patterson, "Stratigraphy of Eocene between Laredo and Rio Grande City, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 2 (February, 1942), p. 256.

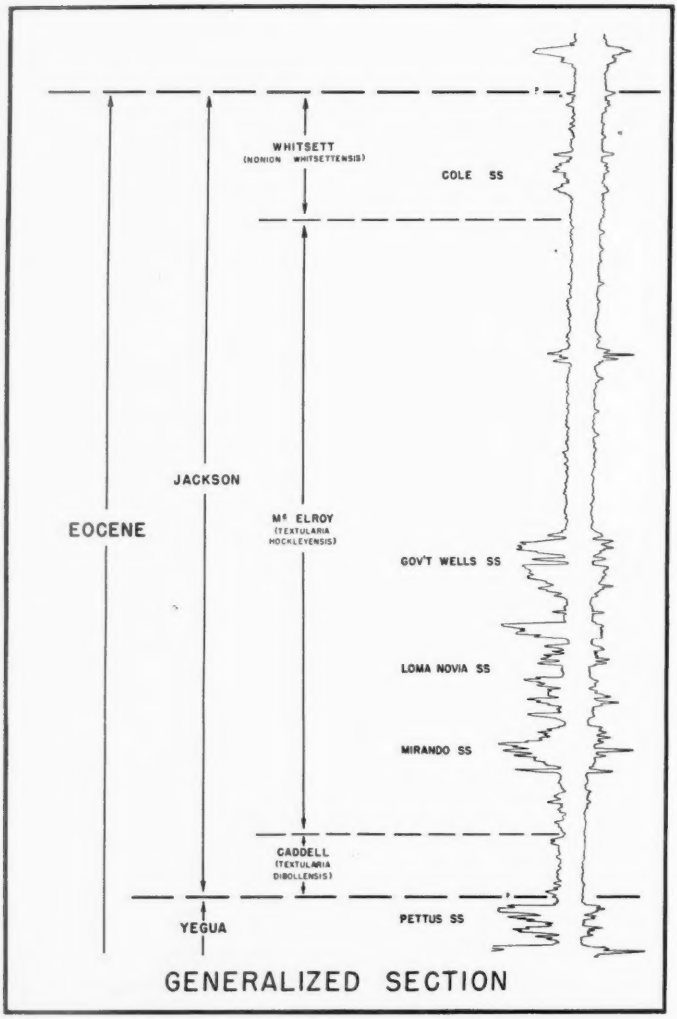


FIG. 2.—Generalized section. Vertical scale: 1 inch equals approximately 300 feet.

bodies varies from approximately 5 to 20 miles and all of the sands thicken basinward. Some of the sand zones consist of two sand bodies separated by shale. In this case, the two sand bodies merge updip and eventually pinch out, forming a wedge-shaped sand zone. All of the sands grade laterally as well as vertically into shales and clays which are predominantly lagoonal deposits.

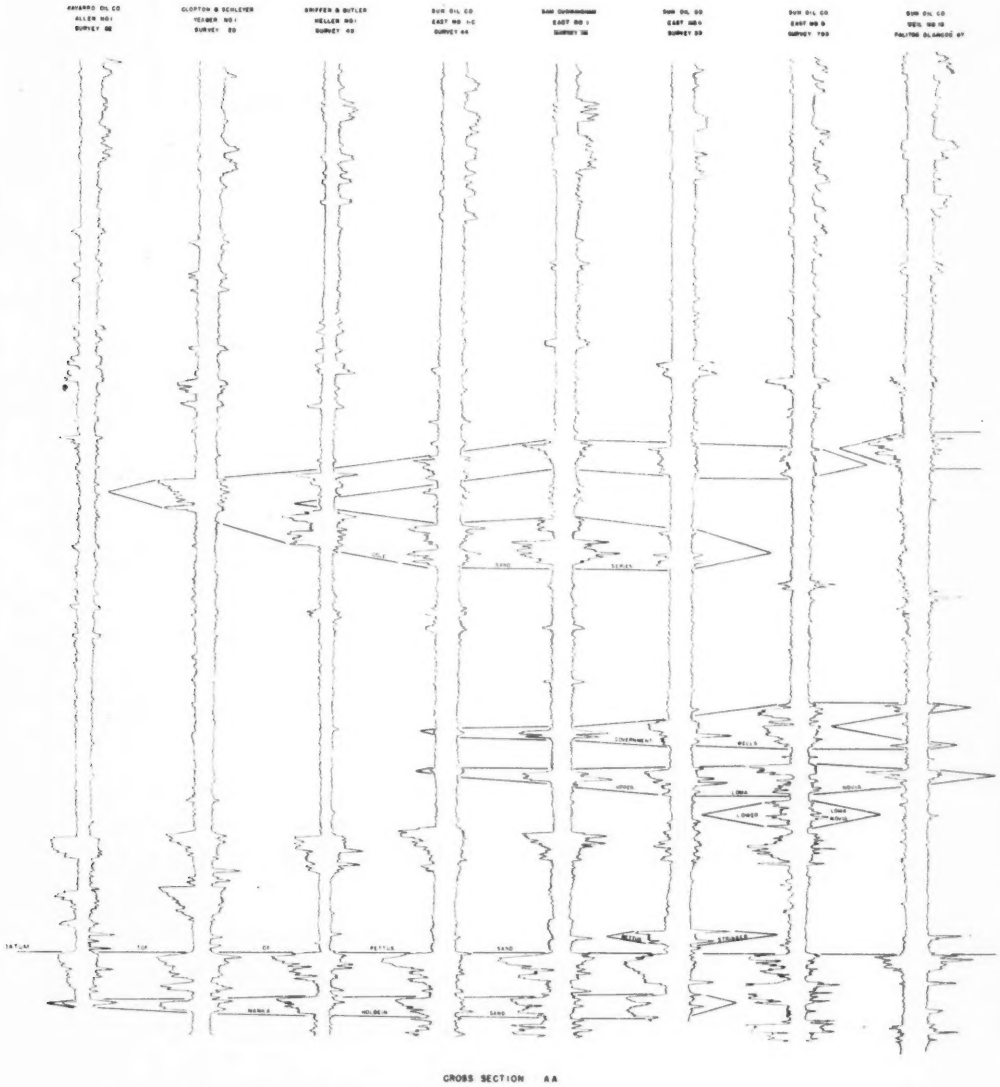
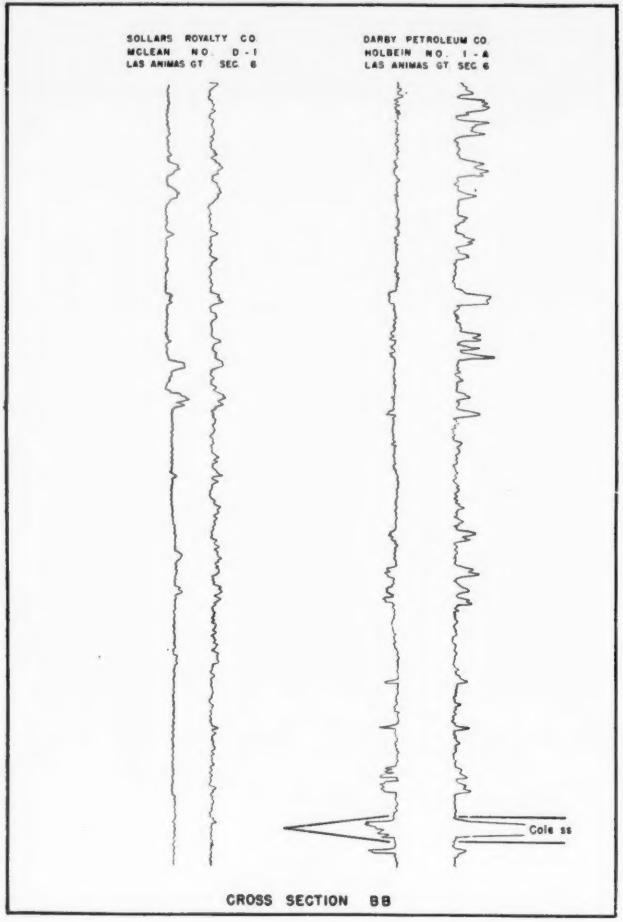
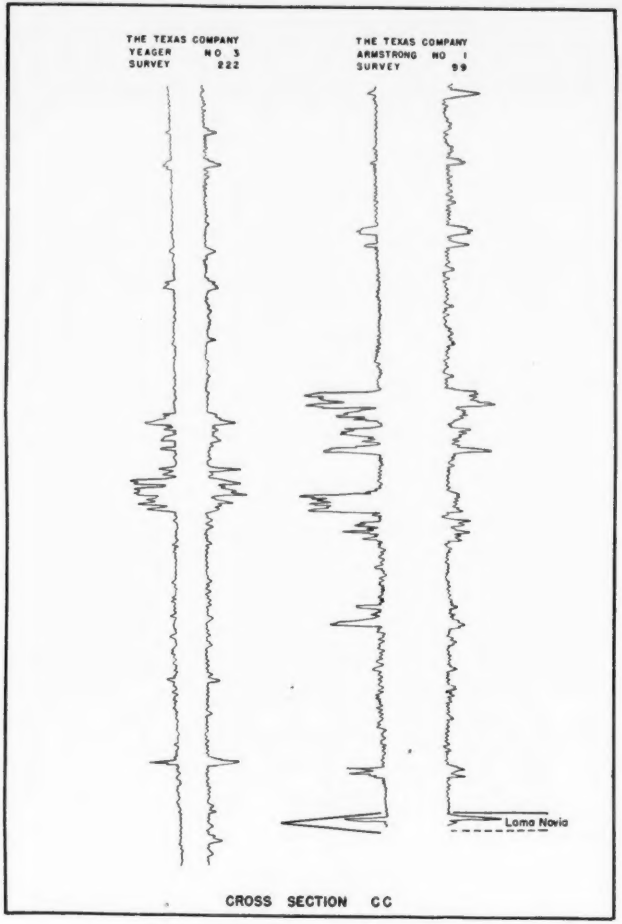


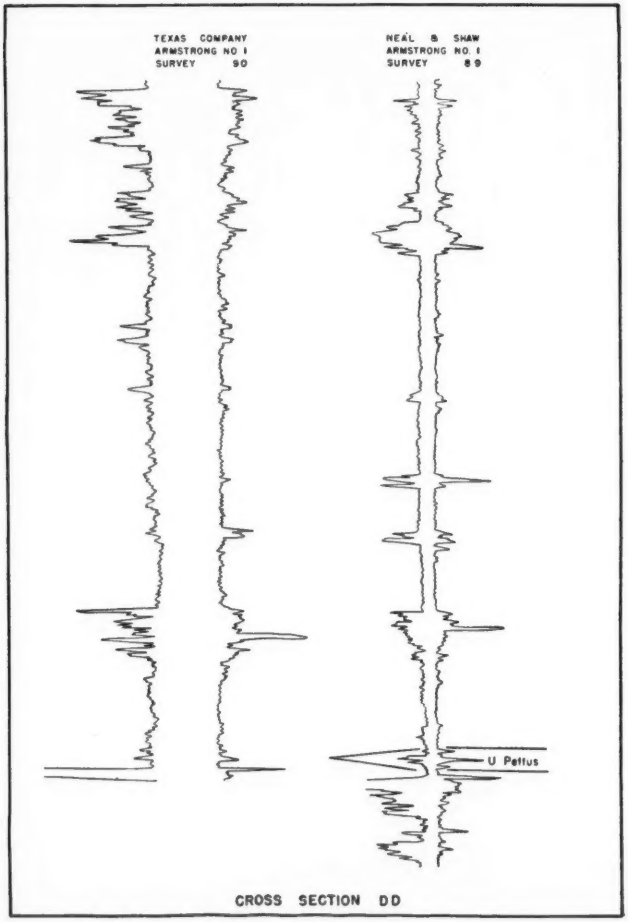
FIG. 3.—(Cross section *AA*.) Cycles of sand deposition. Horizontal scale: diagrammatic. Vertical scale: 1 inch equals approximately 450 feet. Location of section, Figure 7.



CROSS SECTION BB



CROSS SECTION CC



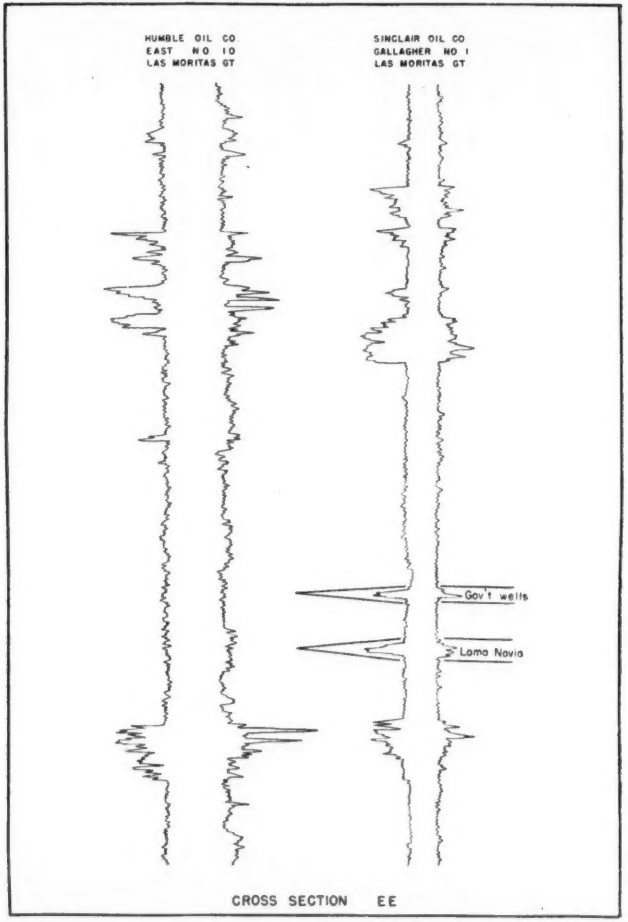


FIG. 4.—(Cross sections *BB, CC, DD, EE.*) Localization of individual strand lines. Horizontal scale: diagrammatic. Vertical scale: 1 inch equals approximately 200 feet. Location of section, Figure 7.

The character and development of these sand zones and their association with the surrounding formations suggest shore-line or near-shore deposition. The zone of lensing-out updip corresponds with the old strand line. These Eocene strand lines are in general parallel with the present coast line.

The alternation of lagoonal shales and clays with sand bodies, the lensing nature of the sands, the character of the surrounding formations, and the relationship between the sands and these formations suggest that sedimentation during the Eocene was characterized by slowly transgressing and regressing seas.

The normal cycle of transgression and regression began with muddy deposits shoreward from contemporaneous sand deposits. These two types of deposits were laid down in wide, muddy, continental-shelf areas separated from the strand line by offshore sandy deposits, in accordance with the lagoon and offshore-bar theory. That the sands migrated slowly is evidenced by the considerable thickness of muddy lagoonal deposits both above and below the sands. Abundant marine life in the muddy deposits suggests that the sand bodies were entirely submarine at times.

Shoreward from the lagoonal deposits, the sediments consist of interbedded clays, shales, and sands. These sediments are characterized by carbonaceous material, lignite lentils, and cross-bedding, all of which indicate deposition under deltaic, estuarine, and non-marine conditions. There is no marked change in thickness as these beds grade into the marine deposits, indicating that they accumulated almost as quickly as the latter.

As the sea retreated, the deposits of sand migrated basinward over the marine shales. In this way the upper sand body of a wedge-shaped sand zone was formed. The lagoonal, or shaly, facies followed the gulfward movement of the sand deposition and this resulted in deposition of shales or muds over the marine sands.

The numerous lensing sands suggest that this cycle of deposition was repeated many times during the Eocene. The areas of sand deposition of each advance and retreat of the sea vary from approximately 5 to 20 miles. The sands which extend basinward only a few miles and consist of only one sand body, suggest a static period of deposition followed by a rapid withdrawal or advance of the sea. Minor fluctuations of the sea resulted in many stringer sands which pinch out downdip from the strand line of the main sand body. These stringers occur both above and below the main sand.

The Cole sand of the Jackson formation is typical of one of the many cycles of deposition. Cross section *AA* illustrates these cycles of deposition. The upper cycle in the diagram (Fig. 3) shows the Cole sand; the middle cycle shows the Government Wells and middle and lower Loma Novia; the lower cycle shows the Pettus and Manila Holbein sand.

STRUCTURE

In general, the structure of the area is simply that of low regional dip toward the coast. The dip ranges from 50 to 150 feet per mile and averages approximately

90 feet per mile. Broad noses are numerous throughout the area; however, no pronounced structure is known to be present. Where control permits mapping on a very small contour interval, small areas of closure are indicated. Those structures present are, for the most part, attributed to irregular compaction, irregularities in shore-line deposition, and irregular contouring surfaces.

FACTORS CONTROLLING ACCUMULATION

In common usage the term "closure" refers to areas outlined by closed structural contours. These areas reveal structural deformation and structural closure. In areas of lensing sands, structural deformation may be absent or may be a

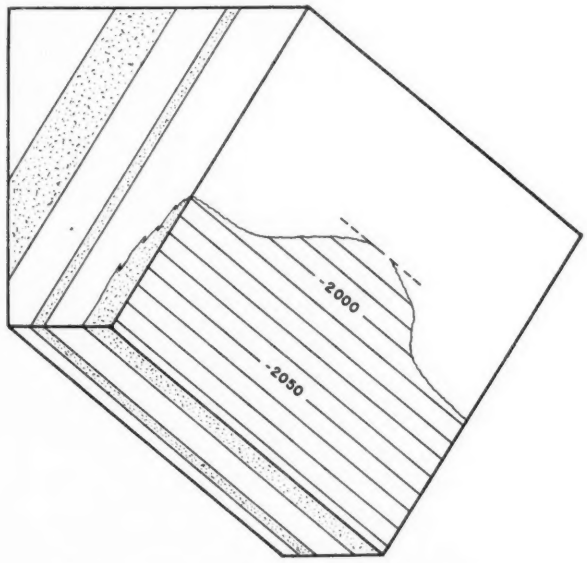


FIG. 5.—Diagrammatic sketch illustrating effective closure.

secondary factor in the accumulation of oil and gas. Where sands lens out updip as well as along the strike, an area is formed which is effectively closed to further migration of oil and gas. The term "effective closure" is here introduced to describe areas closed by lensing sand bodies in which there is an absence of structural deformation. This type of closure is illustrated in a highly diagrammatic sketch in Figure 5.

The map of the Armstrong field (Fig. 6) shows a total effective closure of approximately 175 feet, of which approximately 130 feet is in the producing area.

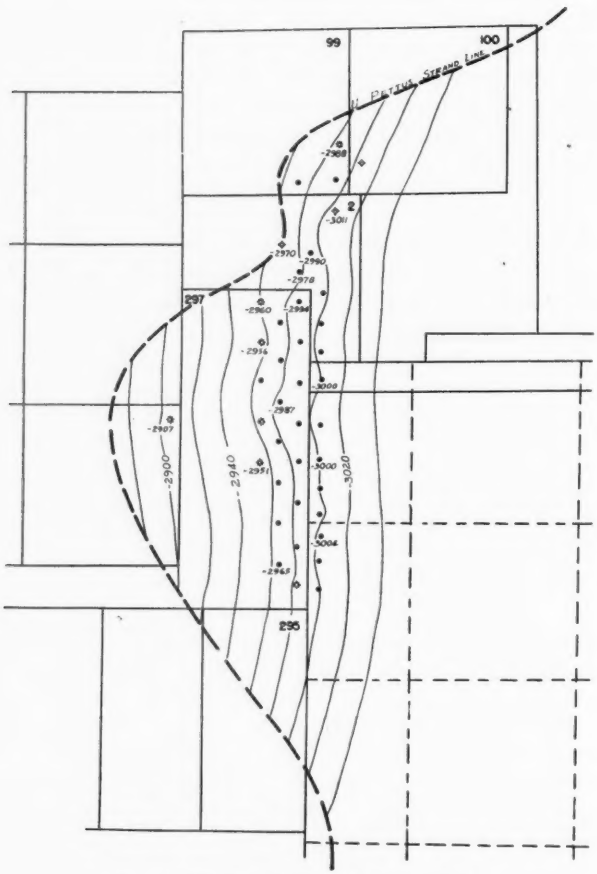


FIG. 6.—Effective closure in Armstrong field.

No structural closure is present. A structural map of the Randado field[6] having a 10-foot contour interval shows two small areas with 10 feet of closure. These closed areas produce only on the updip side. Structural closure is here a secondary factor in the accumulation of petroleum and may or may not serve to localize accumulation along the strand lines.

The strand-line map of Jim Hogg County (Fig. 7) shows that, in each case, the field is situated where the strand line curves in the updip direction. This updip curving of the strand line is the result of a broad shallow re-entrant at the

[6] A. C. Trowbridge, "Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas," *U. S. Geol. Survey Bull. 837* (1932). See map by Lloyd North.

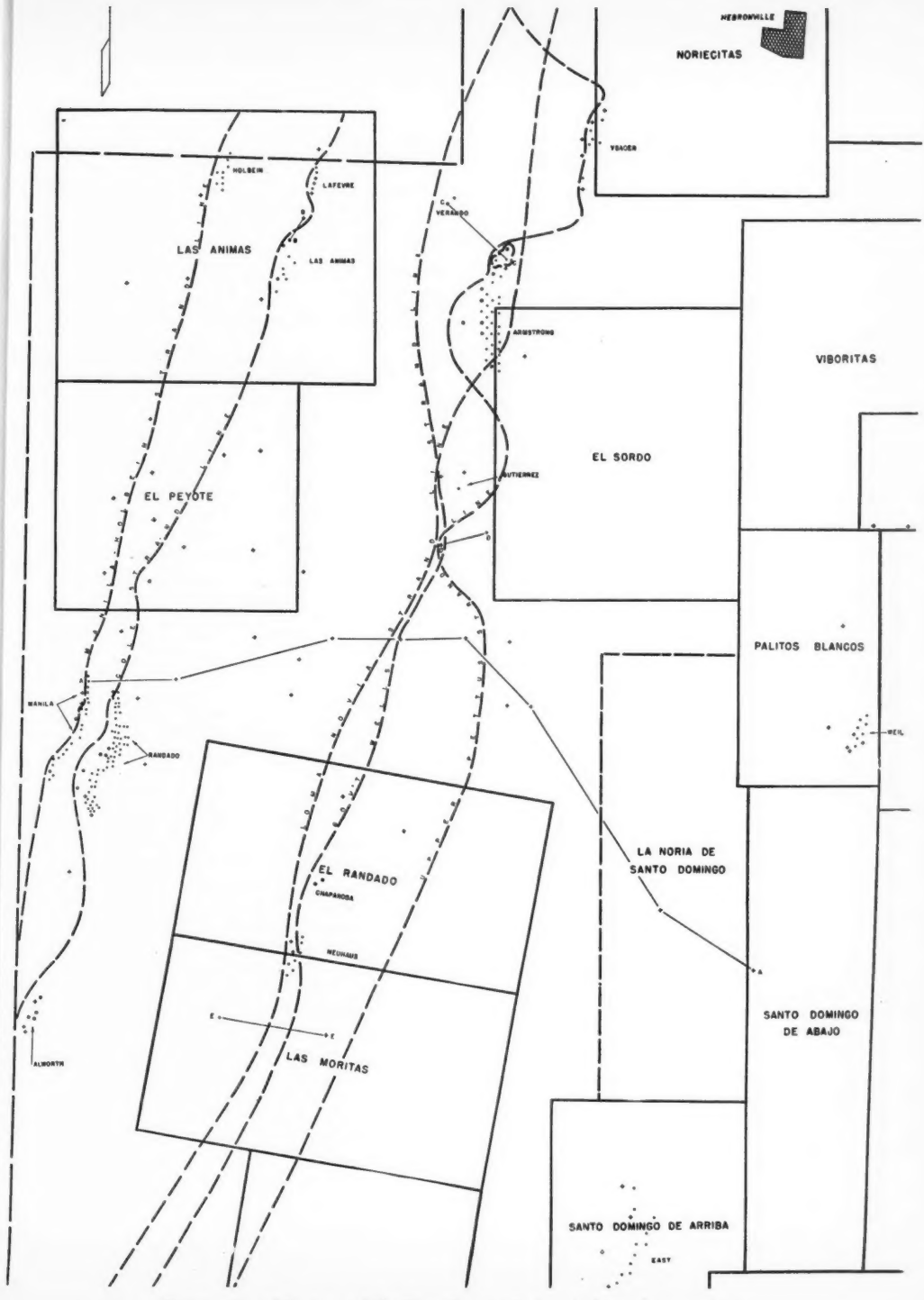


FIG. 7.—Strand-line map of Jim Hogg County. Scale: 1 inch equals 17,500 feet.

time of deposition of the sand. This is especially well shown in the Las Animas and Lafevre fields. The two fields are situated at two re-entrants of the strand line which are separated by a narrow zone in which the sand is absent.

CONCLUSIONS

1. The controlling factor in the accumulation of oil and gas in many fields in the Laredo district of Texas is that of old strand lines.

2. Effective closure is present along old strand lines in the area even though structural closure may be entirely absent.

3. The factor of structural deformation in the accumulation of oil and gas in this area is secondary and may or may not have served to localize accumulation along old strand lines.

4. The methods applied in this area are applicable to other areas of similar geologic history.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1271-1282

STRATIGRAPHIC COMMISSION

NOTE 7—RECORDS OF THE STRATIGRAPHIC COMMISSION FOR 1947–1948

AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE

It seems appropriate to publish from time to time brief statements concerning meetings and other activities of the Stratigraphic Commission. Ready availability of such records, even though they are incomplete, serves a useful purpose. Information about plans and procedures adopted by the Commission may be of interest to many geologists and it is hoped that as machinery gets into good working order, benefits derived from operation of the Commission may become numerous and well recognized.

Personnel of the Commission.—A statement on organization of the Commission and its initial personnel was published as Note 1 (MOORE, 1947). According to plans approved by the five sponsoring organizations, three representatives are designated from each such organization. The terms of commissioners are three years, periods of service being so arranged that one representative of each organization is retired each year and his place is filled by a new appointment or by reappointment. The participating organizations and their representatives, with years of their appointments, are as follows.

Geological Survey of Canada
L. D. BURLING, 1947
J. M. HARRISON, 1947–1948, 1949–1951
G. S. HUME, 1947–1949
W. A. BELL, 1948–1950
United States Geological Survey
H. D. MISER, 1947
J. B. REESIDE, JR., 1947–1948, 1949–1951
W. W. RUBEY, 1947–1949
J. S. WILLIAMS, 1948–1950
Geological Society of America
H. D. HEDBERG, 1947, 1948–1950
M. N. BRAMLETTE, 1947–1948, 1949–1951
S. W. MULLER, 1947–1949
American Association of Petroleum Geologists
M. G. CHENEY, 1947, 1948–1950
J. G. BARTRAM, 1947–1948, 1949–1951
W. V. JONES, 1947–1949
Association of American State Geologists
P. H. PRICE, 1947
J. T. LONSDALE, 1947–1948
R. C. MOORE, 1947–1949
CHARLES DEISS, 1948–1950
W. M. LAIRD, 1949–1951

Meetings.—Counting the assemblage of representatives in Chicago, in December, 1946, as the first annual meeting of the Commission (MOORE, 1947), the second annual meeting, attended by BRAMLETTE, BURLING, CHENEY, HARRISON, HUME, JONES, LONSDALE, MOORE, PRICE, REESIDE, RUBEY, WILLIAMS (alternate for MISER), was held in Ottawa, Canada, in December, 1947. The third meeting, held in New York in November, 1948, was attended by CHENEY, HEDBERG, JONES, MOORE, REESIDE, STENZEL (for LONSDALE), TOMLINSON (for BARTRAM), WILLIAMS, and WOODRING (for BRAMLETTE). At Ottawa, MOORE and CHENEY were elected as chairman and vice-chairman, respectively, for the ensuing year, and at New York the same officers were re-elected for 1949. Discussion at the meetings was devoted partly to cases which had been presented to the Commission and partly to matters of procedure. Handling of business by correspondence among fifteen commissioners is necessarily arduous but as yet, no provision has been made for oral discussion at annual meetings for preparing scientific actions by the Commission.

Cases before the Commission.—Matters which have been laid before the Commission as subjects for their formal expression of opinion include (1) the definition of the nature and classes of stratigraphic units (Note 2, MOORE, 1947); (2) the naming of subsurface stratigraphic units (Note 4, JONES & MOORE, 1948); and (3) definition and adoption of the terms "stage" and "age" (Note 5, FLINT & MOORE, 1948).

Steps in the initial formulation of a question for Commission consideration, placement of the question on the Commission's docket, publication of the problem, gathering

and circulation of pertinent discussion, and ultimately the consideration by the Commission and formulation of a formal opinion all require much time These steps in procedure are according to plan, however, inasmuch as few if any actions sought from the Commission should be completed hastily. During 1948, however, some delay in consideration of cases has been caused by absence from the United States of the chairman.

Procedure in formulating opinions.—Of general interest to those who are concerned with operations of the Commission is an outline of steps which have been agreed to be necessary for preparation of formal statements issued in the name of the Commission. In order to formulate an expression of judgment constituting a cross section of the opinions of all commissioners, and to publish this expression in the *Bulletin*, the estimated minimum required time, according to a somewhat carefully drawn schedule, is seven months. It may be helpful to understand some of the necessary steps in procedure, and in connection with statements which later are published, to give assurance of the manner in which each commissioner has opportunity to contribute to statements issued by the Commission.

After a problem has been published in preliminary form as a "Note" and time has been given for discussion, it is appropriate for the Commission to initiate steps leading to a formal expression of its judgment on the question. For this purpose, it is agreed that a small subcommittee will be designated to review all pertinent material which has been gathered and to draft a preliminary statement of an "Opinion," "Declaration," or "Recommendation," which is to be issued later in the name of the Commission. The report of this subcommittee will be duplicated and circulated to members of the Commission. A thirty-day period is allowed for study of the draft by commissioners and for sending into the chairman notation of all revisions in the preliminary statement which are judged to be needful. The proposed changes and accompanying comments are circulated for consideration of all other members. When a commissioner returns the preliminary draft, he is asked to vote on whether the Commission shall take action by mail ballot on the final revised draft of the statement or shall defer action until the next annual meeting of the Commission, at which time provision shall be made for oral discussion before taking a vote. The purpose of this arrangement for possible hold-over is to provide opportunity for oral discussion and debate on important matters which can not well be settled by circulation of material in letters. Whether the Commission's statement on the question is to proceed to completion by mail ballot or is to be held over for oral discussion, the original subcommittee has responsibility for preparing a revised draft which takes account of the suggestions received from commissioners. This revised draft is submitted to all members of the Commission, who simply hold it for study if the majority voted for tabling action until the time of the annual meeting, or (if action is not thus postponed) who cast a mail ballot on adopting it. Any desired explanation of his vote or other accompanying remarks may be submitted by each commissioner for publication with the statement of the Commission's action.

All of the pertinent material, including the explanations or comments submitted by individual commissioners, is organized by the chairman for publication. Within sixty to ninety days after the time he has submitted it, the statement and accompanying material may appear in print.

Revision of the Code.—Present judgment of the Commission is that attention should be directed to specific questions referred to it and to individual problems which the Commission itself may initiate for study. Within the next two or three years it may be advisable to undertake a general revision of the "Code" (ASHLEY *et al.*, 1933) and it is the sense of the Commission, expressed by action taken at the New York meeting, that re-publication of the revised Code from time to time—say, at five- to seven-year intervals—is desirable, not only with the object of keeping it abreast with progress in stratigraphic science, but in having material published in the Code conveniently available for use of geologists generally.

REFERENCES

ASHLEY, G. H., *et al.*, 1933, "Classification and Nomenclature of Rock Units," *Bull. Geol. Soc. America*, Vol. 44, pp. 423–59; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, pp. 843–68; republished 1939, Vol. 23, pp. 1068–88.

FLINT, R. F., AND MOORE, R. C., 1948, "Note 5—Definition and Adoption of the Terms Stage and Age," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, pp. 372–76.

JONES, W. V., AND MOORE, R. C., 1948, "Note 4—Naming of Subsurface Stratigraphic Units," *ibid.*, Vol. 32, pp. 367–71.

MOORE, R. C., 1947, "Note 1—Organization of Objectives of the Stratigraphic Commission," *ibid.*, Vol. 31, pp. 513–18.

———, 1947, "Note 2—Nature and Classes of Stratigraphic Units," *ibid.*, Vol. 31, pp. 519–28.

Prepared for the Commission by RAYMOND C. MOORE, *chairman*

NOTE 8—AUSTRALIAN CODE OF STRATIGRAPHICAL NOMENCLATURE

AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE

Geologists of North America, as well as those working in other continents, are likely to be interested in the efforts of geologists "down under" in British Australasia to formulate rules for classification and nomenclature of rocks of all types being studied in that part of the world.

At a meeting of the Australia and New Zealand Association for the Advancement of Science at Adelaide, Australia, in 1946, a committee was appointed for the purpose of studying questions of stratigraphical nomenclature. Members of this committee included Prof. W. N. BENSON, Dr. W. R. BROWNE, Prof. S. W. CAREY, Dr. R. W. FAIRBRIDGE, Dr. N. H. FISHER, Dr. DOROTHY HILL, Dr. F. A. SINGLETON, Mr. R. C. SPRIGG, Dr. C. TEICHERT, Dr. J. MARWICK, Dr. F. W. WHITEHOUSE, with Dr. M. F. GLAESSNER as secretary. This committee submitted a report at the 1947 meeting of the Association, held in Perth, Western Australia. A resolution passed at this meeting and approved by the general council of the Association provides for establishment of a Standing Committee on Stratigraphical Nomenclature which seemingly is designed to serve for Australasian geology the functions performed in North America by the American Commission on Stratigraphic Nomenclature.

The following draft of the proposed Australian Code of Stratigraphical Nomenclature was prepared by Dr. M. F. GLAESSNER, Dr. H. G. RAGGATT, Dr. C. TEICHERT, and Dr. D. E. THOMAS. It has been published (GLAESSNER *et al.*, 1948) for the information of geologists in Australia and New Zealand and as basis for the Code presumably to be issued by the Standing Committee on Stratigraphical Nomenclature. As noted in the report (GLAESSNER *et al.*, 1948, p. 7), there is "growing recognition of the necessity for definition and more precise use of *time* and *time-rock* terms" and "for adoption in Australia of a classification of *rock* units based in general on the principles enunciated in similar codes in the U.S.A. and Canada. . . . There are many who find difficulty in distinguishing clearly between *rock* and *time-rock* units. In particular, the term 'Series,' though correctly defined in standard texts as a major subdivision of a 'System,' is used both in that sense and as a *rock*-term describing almost any thick sequence irrespective of consideration of the time interval during which the rocks were deposited."

AUSTRALIAN CODE OF STRATIGRAPHICAL NOMENCLATURE

I. INTRODUCTION

1. In order to cover the practical needs of the stratigrapher in subdividing, classifying and naming stratigraphical sequences, three categories of stratigraphical terms are required: time terms, time-rock terms, and rock terms.

2. Time terms refer to divisions of geological time. All time terms taken together should, therefore, cover the whole of geological time.

3. Time-rock terms are applied to the sum total of sedimentary and extrusive igneous rocks, irrespective of their lithology, formed during a period of time covered by the corresponding time term.

4. Rock terms are required to designate stratigraphical units of a certain lithological uniformity which are easily recognizable as such in the field. They are defined and named with no special reference to their time of deposition.

II. Time Units and Time-Rock Units

1. *Era* is the term customarily used for major subdivisions of geological time, e.g., Proterozoic Era, Palaeozoic Era, Mesozoic Era, etc. There is no generally accepted corresponding time-rock term. The term Group was once favoured, but is not used now in this sense.

2. *Period* is the term applied to a major subdivision of an Era. The rocks deposited during a Period are called a *System*, e.g., Cambrian Period, Cambrian System. Period and System terms should preferably be of world-wide application, although this may not be possible in the case of the Pre-Cambrian (e.g., Nullagine Period and System).

3. *Epoch* is the term applied to a major subdivision of a Period. The rocks accumulated during an Epoch are known as *Series*, e.g., Lower Devonian Epoch and Series.

Epoch and Series terms should also preferably be of world-wide application, but terms of intracontinental validity may be used where correlation on a wider basis is difficult or impracticable, e.g., Yilgarn Epoch and Series.

4. *Age* is the term applied to a major subdivision of an Epoch. The rocks deposited during an Age are called a *Stage*. In theory, Age and Stage, being respectively time and time-rock terms, identified on the basis of their fossil content or of that of the overlying and underlying beds, should be of world-wide applicability. In practice it is often impossible to correlate the rocks which have been deposited during such a comparatively short time in different parts of the world. In such cases it may be necessary to set up local time scales in terms of local sequences for the finer subdivisions of geological time, independent of the scales recognized elsewhere, e.g., Janjukian Age and Stage. Age and Stage terms established for local or intracontinental use should be abandoned as soon as definite correlation with one of the international units has been established beyond doubt.

5. No standard terms for time divisions below the rank of Age are recommended.

6. The term *Substage* is recommended for a subdivision of a Stage. The same considerations apply here as set out above for the use of the term Stage.

7. The term *Zone* should be used in a time-rock sense for a subordinate unit not exceeding the magnitude of a Stage containing rocks deposited during the time of existence of a particular faunal or floral assemblage. Zones are named after a characteristic genus or species, the name of the fossil being followed by the word Zone (e.g., *Nemagraptus gracilis* Zone).

8. *Naming of Time and Time-Rock Units.*—The names of time and time-rock units are identical. Most names of Eras, Periods and Epochs are well defined and well known. Some names of Epochs and Series are derived from the names of the Periods and Systems of which they form part (e.g., Lower Devonian Epoch and Series); but in general they should be based on geographical names. The names of Series, Stages and Substages may be formed either by attaching the suffix -ian or -an to a geographical name (e.g., Janjukian) or by using the geographical name with the appropriate unit term (e.g., Burindi Series).

III. Rock Units

1. The fundamental rock unit to be used in classifying, describing and mapping stratigraphical sequences is the sedimentary formation which is a lithological unit produced by essentially continuous sedimentation. It is proposed that the following criteria, mainly modelled on suggestions developed by the Geological Survey of Canada in 1942, be observed in the description and definition of a formation:

(*a*) *It must contain no apparent evidence of an appreciable break in deposition.* The presence of one or more beds or groups of beds of volcanic origin within a sedimentary sequence is not evidence of an interruption of continuous sedimentation if other supporting evidence is lacking. Interruptions due to contemporaneous erosion are not evidence of appreciable breaks in deposition. Palaeontology may, in some instances, afford the sole evidence of an appreciable break in the process of continuous sedimentation.

(*b*) *In its simplest form it consists dominantly of one kind of rock* as, e.g., conglomerate, sandstone, limestone, etc., or, in some instances, of a variety of one of these rock types distinguished by some special feature or features. *But it may include different kinds of rock* where these individually are too thin, lenticular, or variable in composition to be themselves ordinarily selected as formations. Commonly, where a sedimentary formation contains beds of different kinds of rocks, some or all of these alternate in a regular or irregular fashion.

(*c*) *Recognition of the same formation in different areas is justified when its essential lithological definition is applicable.* Naturally, some variation in lithology is permissible, but a formation must continue to be definable in terms of the dominant kind or kinds of rocks that compose it in its type section or area (see paragraph 2). If, for example, a limestone formation is proved to interdigitate with or grade into shale, the latter must be regarded as representing another formation, but the boundaries between it and the limestone may have to be chosen arbitrarily.

(*d*) *The upper or lower contacts of a sedimentary formation may transgress laterally horizons of neighbouring formations.* Where this occurs, and so long as the lithological identity of the formation is maintained the formation continues to bear its original name, as long as it is practicable to recognize it as an independent unit.

(*e*) *The top and bottom of a sedimentary formation are defined either by a change in lithology or by evidence of an appreciable interval of non-deposition.* In a gradational sequence the passage beds from one formation to another may be sufficiently distinctive and extensive to be considered as separate, intervening formations.

(*f*) *A formation may hold one or more faunas or floras.* Lithology, not palaeontology, defines the vertical limits of formations except as indicated in (*a*) above.

(*g*) *A sedimentary formation may include minor developments of volcanic rocks*, provided these cannot be recognized as marking an appreciable interval in the process of sedimentation, and provided they are not regarded as integral parts of the formation.

(*h*) *Pyroclastic materials*, whether deposited in water or on land, are to be regarded as volcanic sediments and, hence, may be recognized as sedimentary formations.

2. *Igneous* and *metamorphic* rocks should be classified and named according to the same principles as sedimentary rocks as far as stratigraphical methods can be applied to their study. The petrological character of such a rock will provide the basis for its definition as a formation, e.g., Flinders Basalt.

3. (*a*) As far as possible the name of a formation shall consist of a geographical name coupled with a lithological term which is descriptive of the rock, as is already widely done in Australia. Examples: Gingin Chalk; Wianamatta Shale; Brighton Limestone; Bunya Phyllite.

(*b*) The term *Formation* should be used as part of the name only where the lithological character of the beds cannot be properly described by one lithological term. Such units have in the past in Australia been variously referred to as beds, series, group or stage.

(*c*) The rule to name formations after localities may be relaxed, but only when absolutely necessary, in areas where insufficient geographical names are available. It is suggested that in such cases either fossil names or else rock characters other than lithology may be applied.

(*d*) To assemblages of volcanic rock consisting of lavas and pyroclastic rocks of different kinds the term *volcanics* in conjunction with a geographical name may be applied, e.g., Mt. Devlin Volcanics.

(*e*) Where a large mass is composed mainly of diverse rocks including igneous or metamorphic rocks or both, or is characterized by very complex structures, the term *Complex* may be used.

(*f*) Each new formation that receives a formal name must be explicitly defined at the time of its proposal, though this rule shall not be construed as invalidating well-established names. The definition must cite the geographic feature from which the name is taken. It must also cite a specific locality at which the unit is typically developed, and should include a statement of the important facts that led to the discrimination of the formation and a statement of the characteristics by which it may be identified.

(*g*) Subsurface units shall be given formal names only where names are necessary for adequate presentation of the geological history of the region.

4. In case of synonymy the rule of priority should apply, that is, if it is found that two authors have given different names to the same rock unit, the name chosen by the earlier author should be the valid one. Application of this rule should, however, be restricted to cases where no reasonable doubt as to the identity of the opinion of the authors exist and where the two names have actually been defined on the basis of field observations.

5. A Formation name shall not necessarily be invalid if it is found that it has previously been used for another rock unit of different age in another part of the country. The use of identical Formation names for rock units of different age is, however, to be avoided.

6. The term *Group* may be applied to a sequence of two or more Formations. Rules for the naming of Groups shall be the same as those for Formations, except that in all cases Group names should be geographical names. Where an assemblage of unsubdivided strata is designated a group, the possibility of its later division into formations is implied.

7. A formation may be subdivided into lithologically distinct *Members*, *Lenses*, or *Tongues*, according to the lateral extent of the subdivisions. No special rules shall apply to the naming of such subdivisions, which will usually be of purely local significance.

8. The term *Beds* shall be retained as a general term for stratigraphical units or complex sequences which have not been well defined and are incompletely known as to their thickness and detailed lithological succession. In the naming of Beds the same rules shall apply as for Formations. As far as pos-

sible the original name shall be preserved if further investigations lead to a better definition of the sequence as Group, Formation, or any other unit.

Note: In harmony with prevailing practice in British countries, both parts of the names of time, time-rock, and rock units shall begin with capital letters.

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Prepared for the Commission by RAYMOND C. MOORE, *chairman*

NOTE 9—THE PLIOCENE-PLEISTOCENE BOUNDARY

AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE

A subject of stratigraphical classification and nomenclature having widespread interest to geologists concerns definition of the boundary between deposits of Pliocene and Pleistocene ages.

Discussion at International Geological Congress.—Special attention was given to this problem in meetings of the recent 18th International Geological Congress, held in London during the last week of August, 1948. Papers focused on criteria for definition of the Pliocene-Pleistocene boundary and describing this part of the column in Europe, Africa, Asia, Australia, North America, and South America were read. In addition, a temporary commission was appointed by the Council of the Congress for the purpose of reviewing available evidence and making whatever recommendations on recognition of this boundary which seemed appropriate: Bechuanaland—E. J. WAYLAND; Denmark—K. MILTHERS; France—G. DUBOIS; Great Britain—A. T. HOPWOOD, W. B. R. KING, K. P. OAKLEY, D. M. S. WATSON, F. E. ZEUNER; India—D. N. WADIA; Italy—C. I. MIGLIORINI; Kenya—L. S. B. LEAKEY; Netherlands—I. M. VAN DER VLERK; United States—KIRK BRYAN, H. L. MOVIUS, JR., L. L. RAY. Brief preliminary reports on the Pliocene-Pleistocene symposium and work of the Commission have been published (OAKLEY, 1949; KING & OAKLEY, 1949).

W. B. R. KING (Cambridge University), who acted as chairman of the symposium, outlined various criteria proposed for delimiting Pleistocene and Pliocene rocks and stressed desirability of selecting a type area. Features of the late Cenozoic geologic record in Italy seem best suited to serve as a standard in definition of the Pliocene-Pleistocene boundary. In terms of this Mediterranean region, however, question arises as to whether this boundary belongs at the base or top of marine deposits called *Calabrian*, and correspondingly, at the base or top of equivalent continental fossil-bearing deposits called *Villafranchian*.

Review of the stratigraphy of Villafranchian deposits of Italy and of eastern and central France by H. L. MOVIUS (United States) indicated that they are approximately contemporaneous with the beginning of glaciation in the Alps. C. I. MIGLIORINI (Italy) described the marine succession of undoubted upper Pliocene (*Astian*) deposits and unconformably overlying Calabrian strata, followed by deposits called *Sicilian*. Stratigraphical and paleontological analysis indicates that the change which is most marked occurs at the base of Calabrian beds and change at this point is accompanied by evidence of pronounced climatic cooling. Paleontological distinction between Calabrian and Sicilian strata is scarcely recognized. Accordingly, conclusion is drawn that the Pliocene-Pleistocene boundary should be placed at the contact between Astian and Calabrian deposits. R. SELLI (Italy) on the basis of detailed study in northern Italy differentiated lower Calabrian coldwater beds which he regarded as equivalent to pre-Günz and Günz, earliest Pleistocene, and above these deposits (upper Calabrian or *Emilian*) containing a mild-climate fauna representing a post-Günz pre-Sicilian part of the Pleistocene.

Paleontological evidence for classing Villafranchian beds as lowermost Pleistocene was summarized by A. T. HOPWOOD (Great Britain) who stressed the importance of new elements in its widespread mammalian fauna, including *Elephas*, *Equus*, and advanced bovines. This assemblage is distinguishable on different continents. M. FRIANT (France) emphasized importance of the elephants as guide fossils of the Pleistocene. H. E. THALMANN (Venezuela), in discussing foraminiferal evidence of a Pliocene-Pleistocene boundary, noted that five genera of Foraminifera (*Bifarinella*, *Geminospira*, *Oolitella*, *Polymorphinoides*, and *Unicosiphonia*) are restricted to Pleistocene deposits. T. M. STOUT (United States) described the sequence of late Cenozoic vertebrate faunas of Nebraska, Kansas, and Texas, concluding that the deposits called Ash Hollow and Kimball (Ogallala) in Nebraska are definitely correlatable with Astian (upper Pliocene) continental formations of Europe and that overlying Broadwater or Blancan deposits correspond to the Villafranchian of Europe. The line between Pliocene and Pleistocene is judged to belong between uppermost Ogallala and Broadwater or Blancan deposits.

Geomorphological and stratigraphical evidence cited from several parts of the world seems convergent in pointing to the boundary at the base of Calabrian (or Villafranchian) deposits as the most logical boundary between Pliocene and Pleistocene. Thus, as outlined by G. L. S. SIBINGA (Netherlands), definition of the beginning of Pleistocene time in the East Indies is best recognized on the basis of eustatic marine regression. In Patagonia, marine terraces, capped by mollusk-bearing deposits, were described by E. FERUGLIO (Argentina). Deposits on upper terraces (170–186 m., 115–140 m.) contained 30 to 40 per cent of extinct species and are regarded as Upper Pliocene. Oldest terraces judged to be Pleistocene in age occur at elevation of 45–95 m. and younger ones at 15–30 m. and 8–12 m.; these are associated with molluscan beds having successively smaller proportions of extinct species.

L. S. B. LEAKEY (Kenya) reported that Kageran Stage deposits of East Africa containing a Villafranchian fauna also yield human artifacts representing the earliest known cultures and it is logical to regard these deposits as early Pleistocene. Deposits of Java containing three giant types of early fossil men as described by G. H. R. VON KOENIGSWALD (Netherlands) are now generally classed as Lower Pleistocene, but the Trinil beds, in which remains of *Pithecanthropus erectus* were found, are judged to be middle Pleistocene, equivalent to the Choukoutian Stage of China. As noted by C. C. YOUNG (China) the base of the Choukoutian deposits is defined as the lower limit of the Pleistocene in that region. According to D. N. WADIA (India), no definite break between Pliocene and Pleistocene can be found in the thick Siwalik deposits of the northwestern Sub-Himalayas.

In Holland and the East Anglia region of England, stratigraphic and foraminiferal evidence reported by I. M. VAN DER VLERK and A. J. PANNEKOEK (Netherlands) indicates a marked recession of the sea between Poederlian (middle Red Crag or Newbournian) and overlying Amstelian (upper Red Crag or Butleyan) marine deposits. This boundary corresponds to the Astian-Calabrian boundary and is best recognized as the line of division between Pliocene and Pleistocene. Continental deposits (Pretiglian) of the Netherlands which are equivalent to Amstelian contain the oldest elephants found in this North European section.

Recommendations of the International Congress Pliocene-Pleistocene Commission.—The temporary commission appointed by the Council of the International Congress was able to formulate a unanimous recommendation concerning the Pliocene-Pleistocene boundary which is as follows.

(1) The Commission considers that it is necessary to select a type-area where the Pliocene-Pleistocene (Tertiary-Quaternary) boundary can be drawn in accordance with stratigraphical principles.

(2) The Commission considers that the Pliocene-Pleistocene boundary should be based on changes in marine faunas, since this is the classic method of grouping fossiliferous strata. The classic area of marine sedimentation in Italy is regarded as the area where this principle can be implemented best.

It is here too that terrestrial (continental) equivalents of the marine faunas under consideration can be determined.

(3) The Commission recommends that, in order to eliminate existing ambiguities, the Lower Pleistocene should include as its basal member in the type-area the Calabrian formation (marine) together with its terrestrial (continental) equivalent the Villafranchian.

(4) The Commission notes that according to evidence given this usage would place the boundary at the horizon of the first indication of climatic deterioration in the Italian Neogene succession.

The Type Pliocene and Pleistocene.—Despite scant attention paid by geologists at the Congress to the history of the terms Pliocene and Pleistocene, the original definitions and designations of the type localities obviously merit notice. If present-day judgment indicates need to revise initial concepts, such revision can be made, but if present-day judgment confirms early definitions, so much the better.

LYELL (1833) introduced divisions of the Tertiary rocks which he designated "Older Pliocene" and "Newer Pliocene" (original quoted by WILMARTH, 1925, p. 51), indicating the Subappenine strata of northern Italy as type of the "Older Pliocene" and the island of Ischia and Val di Noto (Gulf of Naples region) as type of the "Newer Pliocene" (SCHENCK, 1935, p. 532). Later, LYELL (1839) substituted Pliocene for "Older Pliocene" and introduced Pleistocene to replace his "Newer Pliocene."

The type locality of Pliocene ("Older Pliocene") rocks contains good outcrops of fossiliferous deposits now called Plaisancian, below, and Astian, above, overlain by fossil-bearing Calabrian and Villafranchian beds. Italian geologists have assigned this entire succession to the Pliocene (GIGNOUX, 1943, p. 552).

The type locality of Pleistocene ("Newer Pliocene") exhibits the celebrated marine Epomeo marls, which are now demonstrated to be equivalent to Calabrian. Calabrian locally interfingers with Villafranchian strata and is recognized as the marine equivalent of Villafranchian.

Thus classification of Pliocene and Pleistocene as defined by LYELL and as illustrated by the type localities selected by him accords with conclusions of geologists participating in the Pliocene-Pleistocene symposium and formulating recommendations of the temporary commission on this subject at the International Geological Congress.

The Pliocene-Pleistocene Boundary in North America.—Fossil-bearing late Cenozoic deposits representing Pliocene and Pleistocene time are found in several parts of North America, some of the most important for purpose of stratigraphic classification being in the Ogallala, Blanco, and associated deposits of the central Great Plains region. The Ogallala contains a well defined Pliocene vertebrate assemblage equivalent to Plaisancian and Astian stages of the European Pliocene. Although the Blanco and equivalent deposits of the Plains region generally have been interpreted by vertebrate paleontologists as upper Pliocene, present judgment (MCGREW, 1944; MEADE 1948; SCHULTZ & STOUT, 1948) indicates that the vertebrate fauna actually belongs to early Pleistocene and there is agreement in correlating Blancan fossils with those which characterize the Villafranchian deposits of southern Europe (MCGREW, 1944, p. 47; SIMPSON, 1948, p. 623; SCHULTZ & STOUT, 1948, p. 571).

Deposits established as age equivalents of the Blanco formation (type locality in Texas) are termed Rexroad formation in Oklahoma and southwestern Kansas, Chase Channel formation (Holdrege and Fullerton members) in central Kansas, and Broadwater formation or Holdrege and Fullerton formations in Nebraska. Workers in the Great Plains region agree that Blancan corresponds to Nebraskan and early Aftonian time as defined in the glaciated region of north-central United States (EVANS & MEADE, 1945; FRYE, SWINEFORD & LEONARD, 1948; SCHULTZ & STOUT, 1948).

In the Gulf Coast region, the Pliocene-Pleistocene boundary is judged to belong between the Citronelle formation, below, and Williana deposits, above; and beneath Lissie

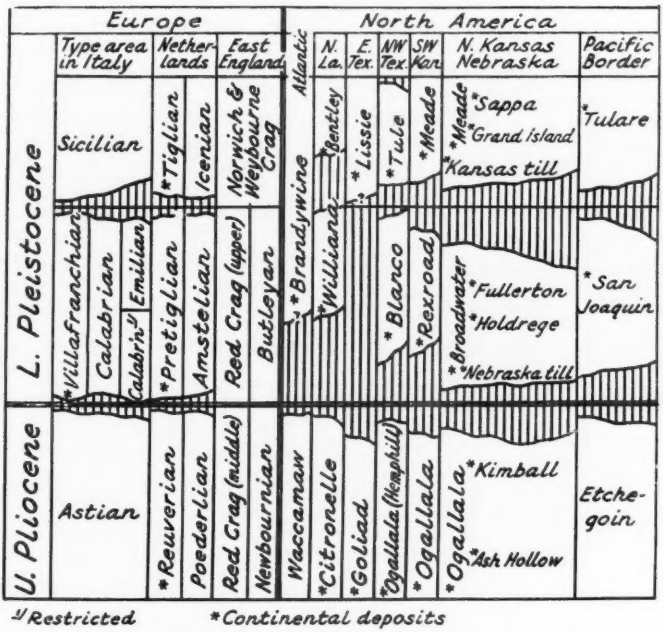

FIG. 1.—Comparison of upper Pliocene and lower Pleistocene deposits in Europe and North America.

(possibly beneath Willis sand) and above Goliad deposits of the Texas coastal region. In Florida and along the Atlantic coastal border, the Pliocene-Pleistocene boundary, presumably equivalent to the base of the Calabrian-Villafranchian deposits of Europe, is between Pliocene beds variously called Caloosahatchee, Alachua, Charlton, Waccamaw, and Croatan and overlying deposits classed as Pleistocene (Fort Thompson, Brandywine) as indicated by COOKE *et al.* (1943, pl. 1).

In the Pacific Coast area, the Pliocene-Pleistocene boundary, as defined by the line between Ogallala and Blancan or that between Astian and Villafranchian (Calabrian), belongs below the San Joaquin clay, rather than at its top, for the San Joaquin beds contain a Blancan fauna (WOODS *et al.*, 1941, pl. 1 and confirmed by other vertebrate paleontologists). This placement of the base of Pleistocene deposits differs from that shown on the chart of WEAVER *et al.* (1944, pl. 1) by transferring the San Joaquin and equivalent deposits (locally many hundred feet in thickness) from upper Pliocene to lower Pleistocene, Pliocene being restricted to Jacalitos and Etchegoin deposits and equivalents. In the Los Angeles basin, no evidence seems to exist for change in the generally assigned placement of the Pliocene-Pleistocene boundary which is drawn between marine Pico beds, below, and predominantly marine San Pedro deposits, above. At least locally, the San Pedro lies unconformably on Pico.

A tabular comparison of Pliocene and Pleistocene deposits discussed is given in Figure 1.

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Prepared for the Commission by RAYMOND C. MOORE, *chairman*

REPORT 1—DECLARATION ON NAMING OF SUBSURFACE STRATIGRAPHIC UNITS

AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE

Summary

Revision of the articles of the Stratigraphic Code pertaining to naming of subsurface stratigraphic units as published in this Bulletin (Volume 32, pages 367–371, 1948) is approved by the Commission except that Article 17 (d) is to read "When outcropping unnamed beds are discovered which are equivalent and in similar facies to a named subsurface unit, the name of the subsurface unit shall be used."

PRESENTATION OF PROBLEM

A proposal that the American Commission on Stratigraphic Nomenclature revise the provisions in the present code on the Classification and Nomenclature of Rock Units (ASHLEY *et al.*, 1933) having to do with the naming of subsurface stratigraphic units was submitted by WAYNE V. JONES in 1947. After acceptance by the Commission of this proposal as an item on its docket, a statement of the subject was published as Note 4, "Naming of Subsurface Stratigraphic Units" (JONES & MOORE, 1948).

CONSIDERATION BY THE COMMISSION

Except for rather minor suggestions, the proposal has encountered little criticism either from commissioners or others. The question as to whether it is good policy for the Commission to amend the code now or simply to state new principles and defer revision of the code to a later date was considered by the Commission at its meeting in New York on No-

vember 12, 1948. It was judged advisable for the Commission to write revised sections of the code, since to do otherwise might leave the way open for alternate interpretations of the effect of the code of the Reports of the Commission. In accordance with procedure which has been determined for preparing Reports of the Commission on questions brought before it, as explained in Note 7 (MOORE, 1949), the statement here published was drafted for the Commission by a subcommittee consisting of WAYNE V. JONES, chairman, MONROE G. CHENEY, and JOHN G. BARTRAM. It expresses judgment of a majority of the commissioners and thus constitutes an official record of action taken. Only the formal statement of Opinions, Declarations, and Recommendations of the Commission is the subject of votes which are recorded. Discussion which accompanies the Reports is intended to express a consensus of the Commission's views, amplifying and clarifying pertinent subjects, but content of the published discussion is not endorsed or rejected by a commissioner's vote on the formal statement. Each commissioner has the privilege of adding remarks explaining or qualifying his vote and expressing views concerning any matter treated in the discussion.

DECLARATION ON NAMING OF SUBSURFACE STRATIGRAPHIC UNITS

The Commission approves the revised texts as proposed in Note 4 (JONES & MOORE, 1948) with the single exception that Article 17 (d) is revised to read as follows:

(d) When outcropping unnamed beds are discovered which are equivalent and in similar facies to a named subsurface unit, the name of the subsurface unit shall be used.

DISCUSSION

The discussion included in the submission (JONES & MOORE, 1948) is deemed to cover most of the points requiring comment and need not be repeated.

A change in wording was made in Article 17 (d) to meet objections raised by several commentators who considered the original wording to be ambiguous.

Chairman MOORE, in a comment attached to the submission as published, pointed out that many of the changes were in the material classed as "Remarks" and thus lacked the force of rules. There was brief discussion of this problem at the meeting of the Commission in November, 1948, and it was the consensus of the group in attendance that the structure of the present code must be maintained unless and until a complete revision is necessary. No one considered that a general revision of the code is desirable at the present time. As a result, no alterations were made in the proposed amendments to the code since they follow the form of the present code very closely. It is true that many of the Remarks are of sufficient importance to be classed as regulations and perhaps as integral parts of the code itself.

ACTION OF THE COMMISSION

Members of the Commission voting for adoption of the Declaration on Naming of Subsurface Stratigraphic Units as here published, include: J. G. BARTRAM, W. A. BELL, M. G. CHENEY, CHARLES DEISS, J. M. HARRISON, H. D. HEDBERG, W. V. JONES, W. M. LAIRD, R. C. MOORE, and J. B. REESIDE, JR. Commissioner G. S. HUME's vote is against adoption of this Declaration and that of Commissioner M. N. BRAMLETTE is for postponing action until the next annual meeting of the Commission. The votes of Commissioners S. W. MULLER, W. W. RUBEY, and J. S. WILLIAMS are for adoption of the Declaration, subject to some revision of wording as stated below.

A majority consisting of thirteen commissioners (two votes qualified—see statements by Rubey and Williams) having voted in favor of adoption, this is cited as official action of the Commission, but attention is called to Section VII of the Articles of Organization and Procedure of the Commission (MOORE, 1947) which states that "An organization mak-

ing designation of representatives to serve as Commissioners shall not be bound in any way to observe procedures or follow judgments expressed by the Commission. Actions by the Commission shall be advisory and involve no commitments by other agencies, either expressed or implied." Explanation of votes or other discussion submitted by individual commissioners follows.

STATEMENTS BY COMMISSIONERS

M. N. Bramlette.—The procedure of considering Declarations at annual meetings seems to me generally preferable, because a more nearly unanimous vote is likely. A few months delay in such matters is of little consequence.

G. S. Hume.—We realize the difficulties involved in naming of subsurface stratigraphic units, but I think where correlations could be made with exposed sections, even if the exposed sections are found after the subsurface formations have been named, the name of the formation as exposed should have priority.

W. M. Laird.—It seems to me that Article 17 (c) could be clarified by phrasing it somewhat in this fashion: "When it becomes possible to correlate a named subsurface unit with a named surface unit and when the surface and subsurface facies are sufficiently similar that two names are unnecessary the name of the more commonly accepted unit should be applied even though some other less well-known name has priority." I believe that this would clear up the matter and would also help in the interpretation of Article 17 (d).

W. W. Rubey.—In my judgment Article 17 (f) (5) should read "Fauna and flora. Diagnostic fossils of the new unit shall be described in detail and, if possible, figured." The following sentence of the draft of this section, reading "Description and figuring of diagnostic fossils are essential if the new unit is a time-rock unit," should be omitted.

J. S. Williams.—I judge that Article 17, Remarks (a), should be modified to read "Subsurface units, recognized and named from well logs, including sample logs and core records, supplemented where practicable by data from electrical or other mechanically recorded logs and by paleontological determination, differ . . . ."

Also, it is desirable that Article 17, Remarks (f) (5) should read "Fauna and flora. Diagnostic fossils of the new unit shall be listed, if known, and if practicable, shall be described and illustrated. This is essential if the new unit is a time-rock unit."

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1283–1284, 1 TABLE

GEOLOGICAL NOTES

DEPTH CLASSIFICATION OF NEW-FIELD WILDCATS DRILLED IN 1948 IN UNITED STATES[1]

FREDERIC H. LAHEE[2]
Dallas, Texas

For several years we have published, in the June number of the *Bulletin*, a summary of statistics on exploratory drilling, but in these annual summaries we have never attempted to break down the total footage drilled in such a way that we could ascertain how the wells might be divided as shallow, moderately deep, and very deep. Since transmittal of our report on 1948 exploratory drilling, we have made a special study of this distribution of depths, and we are now submitting a table which presents this information.

In Table I, only new-field wildcats are considered, and only those drilled in 1948. For each 2000-foot depth bracket, the number of new-field wildcats and their total depth are shown under each state. Thus, in Alabama three such holes were drilled, each less than 2,000 feet deep, and all three with a total depth of 4,892 feet. Four with depths between 8,000 and 10,000 feet were drilled, these four having a total of 35,239 feet. And so on. Totals for the United States are given at the bottom of the table.

We believe that this analysis of depths may be of considerable value, but we do not think a similar table need be published for each year's exploratory drilling. Possibly once every 5 years would be sufficient. Suggestions on this tabulation will be appreciated.

[1] Manuscript received, June 2, 1949.

[2] Chairman, committee on statistics of exploratory drilling.

TABLE I

NUMBER AND FOOTAGE OF NEW-FIELD WILDCATS DRILLED IN 1948 IN UNITED STATES, BY 2,000-FOOT BRACKETS

	0–1,999		2,000–3,999		4,000–5,999		6,000–7,999		8,000–9,999		10,000–11,999		12,000–13,999		14,000–15,999		16,000–17,999		Total New-Field Wildcats Drilled	Total Footage Drilled
	No. Holes	Total Footage	No. Holes	Total Footage	No. Holes	Total Footage	No. Holes	Total Footage	No. Holes	Total Footage	No. Holes	Total Footage	No. Holes	Total Footage	No. Holes	Total Footage	No. Holes	Total Footage		
Alabama	3	4,892	5	15,413	3	15,348	4	24,851	4	35,239									19	95,743
Arizona	1	680	2	4,812	1	4,159													4	9,651
Arkansas	18	22,998	42	125,146	27	131,634	7	47,573	5	43,417	2	22,874							101	393,042
California	55	69,666	76	212,710	53	255,472	24	164,837	15	135,604	5	54,504	4	51,966					232	944,759
Colorado	16	20,148	9	28,369	8	41,779	6	44,428	1	8,286	1	10,544							41	153,554
Florida	4	9,739	2	6,322	9	41,608	2	12,764			4	47,780							21	118,213
Georgia			1	3,916	2	9,865													3	13,781
Illinois	72	82,601	160	463,279															232	545,880
Indiana	80	109,963	135	343,341															215	453,304
Kansas	6	10,226	111	392,600	70	314,566	6	39,070											193	756,462
Kentucky	62	77,329	53	137,034	1	4,257													116	218,620
Louisiana	13	15,569	35	103,699	21	104,339	21	148,268	43	388,218	56	607,331	36	457,970	3	42,398			228	1,867,792
Maryland					1	5,259													1	5,259
Michigan	144	202,633	97	295,568	14	60,156													255	558,357
Mississippi	5	6,989	9	29,220	24	117,581	24	168,598	14	128,105	23	246,262	1	13,251					100	710,006
Missouri	2	3,768																	2	3,768
Montana	11	16,137	8	23,142	5	25,096	4	26,784											28	91,159
Nebraska	1	600	4	11,524	4	18,948													9	31,072
Nevada			1	2,019															1	2,019
New Jersey			1	2,380															1	2,380
New Mexico	11	15,993	37	117,498	22	110,675	4	27,829	4	37,619	4	41,829	2	25,782					84	377,225
North Dakota	1	695			1	5,410													2	6,105
Ohio	7	9,571	15	47,288	13	61,480													35	118,339
Oklahoma	44	58,640	105	309,151	127	623,810	47	315,886	17	152,923	8	86,463	3	38,848	2	29,682	1	17,094	354	1,632,497
Pennsylvania	1	950	5	16,547	7	34,902													13	52,399
South Dakota	1	1,305	2	5,895															3	7,260
Tennessee	46	45,607	8	17,034	1	4,413													55	67,054
Texas	266	340,953	467	1,389,910	471	2,332,869	330	2,276,945	181	1,590,805	72	770,284	15	194,015	1	14,033			1,803	8,909,814
Utah	4	5,375	3	9,355	2	8,990	2	12,400	1	8,678			1	12,145					13	57,003
Virginia	1	1,450	1	2,301															2	3,751
Washington			3	9,664	2	10,527	2	12,886											7	33,077
West Virginia			13	43,116	5	23,906	4	26,734											22	93,756
Wyoming	10	12,234	20	61,242	20	96,511	12	79,217	14	88,967					1	14,309			77	352,480
Totals																				
Wells	885		1,430		914		499		299		175		62		7		1		4,272	
Footage		1,146,771		4,229,495		4,463,560		3,429,130		2,617,861		1,887,871		793,977		100,422		17,094		18,686,181

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1285–1295

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

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*GEOLOGY OF THE LAKE TITICACA REGION, PERU AND BOLIVIA, BY NORMAN D. NEWELL

REVIEW BY W. F. JENKS[1]
Rochester, New York

"Geology of the Lake Titicaca Region, Peru and Bolivia," by Norman D. Newell. *Geol. Soc. America Mem. 36* (1949), IX plus 111 pp., 14 text figs., 21 pls., including 2 geologic maps.

This *Memoir* is the result of a search for new oil in the highest oil field, Pirin. Dr. Newell has brought to light diverse and hitherto unsuspected tectonic elements, as well as a stratigraphic sequence greatly different from that in adjacent areas at the south, southwest, and northwest.

More than half of the volume concerns the stratigraphy of the Titicaca Basin. Numerous measured sections of Devonian to Recent strata are included and in themselves represent a valuable contribution. Careful stratigraphic work throughout the Basin was necessary for a satisfactory solution of the complex structure of the region and of the Pirin oil field.

Long, opposed overthrust faults dip away northeast and southwest from the Titicaca trough, as if the latter had been relatively depressed and at the same time overridden. The faults are in part localized by an even unconformity separating competent Devonian strata of simple structure from incompetent Cretaceous strata of complex structure. In these faults the stratigraphic throw is small, and the horizontal displacement may be small and variable although the disturbed zone is wide. Evidence for overthrusting is clearly presented in Newell's report. This reviewer will add that he is convinced of the presence of overthrusts of this type from his own field studies southwest of Lake Titicaca. Along the Pirin thrust, Middle and Lower(?) Cretaceous beds are thrust northeast over the Tertiary. Above the thrust plane are tightly compressed recumbent folds; below, thick, competent Tertiary clastics are overturned near the fault. Dr. Newell made abundant use of a variety of methods in working out the presence of large blocks of overturned strata in the Pirin field. The small amount of oil which has been discovered in this field is in steeply dipping Cretaceous strata below the fault zone.

Considering the abundance of field evidence, a categoric denial of Newell's conclusions by Arnold Heim[2] is surprising and wholly unjustified. Heim, who had access to Newell's unpublished manuscript and maps, prepared this paper after only four weeks of field work during which he made, to judge by his article, no careful stratigraphic studies. Newell devotes a number of pages to a thorough refutation of Heim's arguments. It should be mentioned that Heim's sections contain abundant examples of geologic relationships possible only in overthrust or overturned sequences, yet he makes no use of this mechanism. He explains some of the inverted relationship by assuming that the Sipin limestone rests in transgressive relationship at the top of the Cretaceous section, instead

[1] Associate professor of geology, University of Rochester. Review received, April 27, 1949.

[2] "Estudios tectonicos en la region del Campo Petrolifero de Pirin," *Bol. Of. de la Dir. de Minas y Pet.*, No. 79 (Lima, 1947).

of at its base, as proved by Newell in places of relatively simple structure. While inaccuracies of detail may be found in Newell's mapping of the Pirin area, as in any first mapping of a complex terrane, his work stands as a reasonably accurate interpretation of the major structural pattern.

A reconnaissance geologic map of the Lake Titicaca region, on a scale of 1:500,000 accompanies Newell's report and will be of great value to all geologists working in the area. Geology of the Pirin area, shown on a map with the scale of 1:30,000, is of special interest as a demonstration of the complexity of local structure along an important overthrust belt.

The Titicaca region is analysed as a potentially petroliferous province, and Newell comes to the conclusion that only the central belt, the Titicaca trough, has any reasonable chance of petroleum accumulation. One is left with the feeling that inadequacy of source material in the most favorable Middle Cretaceous section, combined with the fact that potential reservoirs, where known, are broken by strong faulting, makes the whole Titicaca region unattractive for petroleum exploration.

GEOPHYSICAL CASE HISTORIES, BY THE SOCIETY OF EXPLORATION GEOPHYSICISTS

REVIEW BY CASTLE J. C. HARVEY[1]
Tulsa, Oklahoma

Geophysical Case Histories, Vol. I. Edited by L. L. Nettleton. 680 pp., 448 maps, charts, and figures. Published by the Society of Exploration Geophysicists, Box 1614, Tulsa, Oklahoma (1948). 7×10 inches. Cloth binding. Price, $7.00, postpaid in United States; additional $0.50 outside U. S. Special to A.A.P.G. members: credit price, $6.25; cash price, $6.00.

The publication of this volume is as one writer recently expressed it, "a mile-stone in the history of petroleum exploration." Editor L. L. Nettleton, together with Henry C. Cortes and the Geophysical Case Histories committee of the Society of Exploration Geophysicists, are to be congratulated on the successful completion of their first venture. It was a formidable undertaking on their part to persuade the various companies that the release and publication, of what has generally been considered confidential information, would serve a useful purpose and would not be detrimental to their own or other's interest. Volume I of *Geophysical Case Histories* is a testimonial to the validity and logic of the arguments presented by Mr. Cortes that the services rendered in the past by the Society of Exploration Geophysicists merited the cooperation of the oil companies.

The volume contains sixty papers by sixty-one authors. Twenty of the papers are new and were prepared especially for this volume. Several of those previously published have been revised and brought up to date. The format of the book is generally pleasing and is easily read. The papers are well illustrated by maps showing the results obtained by various geophysical methods, together with final development maps for comparison. A number of the papers include maps of several horizons and different interpretations from the same data. The small print on a number of the maps makes one wish that the maps in this type of publication could be printed on a larger scale. However, considering the great number of maps which are reproduced, the cost would possibly be prohibitive. A separate index for maps and figures is an excellent feature which might well be used by similar publications. Very few errors have been noted. There is an unfortunate scrambling

[1] Atlantic Refining Company. Review received, May 13, 1949.

of paragraphs on pages 70 and 71. The reader will, however, be able to follow through from the context of the paragraphs. The articles are not too technical if the reader understands the general principles and instrumentation of the seismic, gravity, and magnetic methods.

The sixty papers have been grouped under six sections. Section I contains three general and historical papers. Section II deals with Salt Dome Case Histories and contains twenty-one papers, which is the largest number in any one section. The Mid-Continent is represented by seventeen case histories. The Rocky Mountain area and the Foreign section each have four papers, while the California section has eleven.

The papers follow no set editorial form but reflect in their emphasis the varied interests of the authors. For some readers there will be an insufficient amount of geological detail while others will possibly feel that more could have been said concerning the more technical aspects of the various geophysical methods used and described. However, as the editor points out, "the papers are primarily concerned with geophysical results and their comparison with actual geological situations as shown by later developments." The majority of papers are concerned with the results of the seismic method; however, where gravity work was done the results are included in the discussion. Several interesting papers are presented which deal with gravity interpretation alone. There are also several references to magnetometer surveys but none on the air-borne magnetometer. One case history includes the results of a geochemical survey.

To many unfamiliar with the history of the earlier discoveries, the Salt Dome Case Histories will be very interesting for several reasons. Many of these domes have been explored with almost every kind of geophysical method and it is instructive to note the resolving power of the early torsion-balance work and the refraction seismograph as compared with more modern methods. The comparison is not unfavorable on the larger structures. One wonders if the recent deep-water work in the Gulf of Mexico can equal or surpass the record set by the first water-refraction crews of finding seventeen salt domes in a year. In this connection, Eckhardt states that in 1937 two gravimeter crews averaged one salt-dome discovery per week for a string of well over 20 weeks.

Though the fact is not mentioned it is apparent, nevertheless, that the early geophysical discoveries forced a radical change in geological thinking and made many previously held concepts of structure and accumulation untenable. An instance, where a less-favored interpretation proved to be closer to the actual subsurface condition, is given in the history of the Lovell Lake field. The first survey at Tomball was not completed because the low-angle dips "did not indicate the existence of an 'Iowa type' structure." It may be difficult for some to admit, but geophysics has increased petroleum geological knowledge due to the fact that it encouraged drilling where the geological criteria of structure were lacking or not significant. It is possibly true that this knowledge would have eventually become known but it can not be denied that geophysical information accelerated the process. Our knowledge has increased considerably since those early days but there are, no doubt, many instances to-day where producing structures are found but not recognized as such because they do not fit into the accepted geological pattern.

Many arguments arise about the best and least costly method of finding an oil field. Many prefer a rough reconnaissance, others much detail; however, it seems to boil down to the type and size structure which is being sought and the amount of information that is going to be needed for development. It may be said that the work required will be directly proportional to the complexity of the structure and stratigraphy, economic factors not being considered. The Pauls Valley field of Garvin County, Oklahoma, was discovered only after 8½ years of intermittent reflection-seismograph work and drilling. Thirteen dry holes were drilled between the original survey and the final interpretation which led to the discovery. This is an excellent example of the work that is necessary in mapping an area that is complicated by truncation of local structure on a regional uplift. In contrast, the

Antelope field, Clay County, Texas, was outlined in 2 days. The author states that 19 additional days of work did not contribute anything new to the development program. This was part of the original program that surveyed 560 square miles in $8\frac{1}{2}$ crew months and discovered three fields. The Loudon field in Fayette and Effingham counties, Illinois, was mapped in less than 1 month of shooting. Between these extremes are examples which required different techniques and varying amounts of time to solve the problems.

It would not be fair to ignore the fact that this volume deals only with successful, productive surveys. Everyone knows that there have been, and will continue to be, failures. The early successes were spectacular in number and magnitude and, to the uninitiated, it may have seemed that the methods were infallible. The reason for this has been pointed out by many people. The field was virgin and the structures found were of such a relief and magnitude that a larger margin of error could be tolerated, both in interpretation and technique. This is evident in some of the case histories which are presented in this volume. The ratio of failures to successes has been rising and as the area for exploration grows more limited, the ratio will undoubtedly increase. Those engaged in exploration know that the field work is more difficult and the interpretation becoming more complex and less susceptible to routine analysis than in the past. For that reason a compilation of case histories of geophysical failures would be helpful to every one, but since all the factors involved could not be easily accounted for or evaluated, it is not likely that we shall ever see such a volume. It would, moreover, be embarrassing to too many individuals.

Due to the increasing complexity of interpretation, it is becoming more necessary than ever that the geophysicist and the geologist work together as a team. The day when each could successfully stand alone and point with pride at his achievements has long passed. To work together, the geologist and geophysicist must know and understand the problems of each field. Most geologists will have to gain their understanding from reading and studying geophysical case histories such as presented in this volume. It is then going to be necessary for the geologist to know more concerning the applicability of the several geophysical methods and their limitations under various geological conditions. The geophysicist must know to what extent the physical characteristics of the geology of the area is going to affect his results and interpretation. The value of this volume lies in the fact that material presented covers a variety of methods and geological provinces. The geophysical results are compared directly with the actual geological condition as uncovered by the drill. It covers in a compact and concise manner a variety and amount of experience that would be practically impossible for one man to attain in the field. It will therefore be valuable to everyone who seeks to add to the background of experience that is increasingly necessary for successful oil exploration.

THE USES OF SCIENCE, BY E. DEGOLYER

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

"The Uses of Science," by E. DeGolyer. *Southwest Review*, Vol. 34, No. 2 (Dallas, Texas, Spring, 1949), pp. 168–75.

In a concise dissertation, E. DeGolyer has presented his philosophy regarding the utility of the scientific method which has served him so adequately in his career as a petroleum geologist. Years of accumulated knowledge and wisdom have given the background for exhaustive analysis of the nature and use of science and after mature deliberation he has set down painstakingly the conclusions at which he has presently arrived.

[1] Amerada Petroleum Corporation. Review received, May 16, 1949.

Earnest consideration of the scope and responsibilities of this vaguely delimited branch of human knowledge, led DeGolyer to his own characteristically pithy definition: "Science is truth organized in order to make possible human comprehension." Using this broad premise, he proceeds to extend the scope of science far beyond the field of the physical and biological sciences. He then surveys the scientific method of organizing truths, in which he stresses "impartiality of observation and the longest of long views."

DeGolyer assays the technical difficulties in the operation of the scientific method, which arise from incomplete knowledge of the truths to be organized or from the premature acceptance of so-called "laws," but he concludes the method has possibilities of extension into other sciences, such as government, politics and law.

In support of important points which he makes in this dissertation, DeGolyer has made use of pertinent examples from the science of petroleum geology.

This scholarly presentation of the basic philosophy of science and the scientific method of "precise observation, controlled experiment and the exercise of anticipatory sense" should be read by all who are interested in science as a field of human knowledge.

CRETACEOUS AND TERTIARY SUBSURFACE GEOLOGY, BY THE MARYLAND DEPARTMENT OF GEOLOGY, MINES, AND WATER RESOURCES

REVIEW BY STANLEY B. WHITE[1]
Durango, Colorado

*"Cretaceous and Tertiary Subsurface Geology: The Stratigraphy, Paleontology, and Sedimentology of Three Test Wells on the Eastern Shore of Maryland," by many authors. *Maryland Dept. Geol., Mines, and Water Resources Bull. 2* (1948). 456 pp., 30 figs., 39 plates, 20 tables. Baltimore, Maryland. Price, $2.00.

Bulletin No. 2 (1948) of the Department of Geology, Mines, and Water Resources, State of Maryland, the result of studies of subsurface data derived from three test wells for petroleum drilled on the Eastern Shore of Maryland, is one that can not be fairly reviewed without recourse to superlatives.

As this reviewer was intimately connected with the geological and geophysical work that preceded the drilling of The Ohio Oil Company's Hammond well No. 1, he realizes acutely the painstaking efforts that were made in the preparation of this bulletin.

The management of The Ohio Oil Company recognized in 1942 the advantages that would be gained if a discovery of oil could be made on the eastern seaboard, especially during the critical period of submarine warfare, and it ordered the geologic study which led to the drilling of the Hammond well. In addition the company, wishing to be sure that no possible oil field be overlooked in this virgin territory, authorized the continuous coring of the well from a depth of 1,000 feet to 5,568 feet, at which depth it was abandoned in basement rocks. The cores from this well were presented to Joseph T. Singewald, Jr., director, Department of Geology, Mines, and Water Resources, State of Maryland, who recognized their great value, and obtained the necessary funds for their complete study. He enlisted the active help of J. L. Anderson, Julia A. Gardner, Lloyd W. Stephenson, Harold E. Vokes, Kenneth E. Lohman, Joseph A. Cushman, Ann Dorsey (Mrs. Arthur W. Clapp), Robert M. Overbeck, and Frederick M. Swain, all experts in their own right. The result is a precedent-making bulletin discussing the Cretaceous and Tertiary subsurface geology of the Eastern Shore, based on a study of the cores, well-cuttings and electrical logs from the three test wells.

[1] Geologist, The Ohio Oil Company, Durango, Colorado. Review received, May 20, 1949.

The scope of the bulletin embraces a detailed study of the lithology, paleontology, sedimentary petrography, mineralogy, and texture of the cores and cuttings with such thoroughness that a high degree of accuracy can be expected for the deductions made.

J. T. Singewald, Jr., who is to be very highly commended for his foresight in arranging this work and for his untiring efforts exercised in securing its completion, is now well rewarded by the publication of this splendid treatise that will be appreciated by all students of the Cretaceous-Tertiary rocks of the Eastern Seaboard.

DIE TEKTONISCHE ENTWICKLUNG DER PACIFISCHEN RANDGEBIETE, BY H. STILLE *ET AL.*

REVIEW BY W. A. VER WIEBE[1]
Wichita, Kansas

Geotektonische Forschungen, edited by H. Stille and F. Lotze. Heft 7 and 8 (bound in one volume), entitled "Die tektonische Entwicklung der Pacifischen Randgebiete" (The Tectonic Development of the Areas Bordering the Pacific Ocean). Separate articles by H. Stille, G. Y. Lee, H. Kölbel. 323 pp., many maps and diagrams, 3 pls. Published by Gebrüder Borntraeger, Berlin-Zehlendorf (1945). In German.

One of the great petroliferous regions of the world lies in eastern Asia and extends southward and southeastward through the East Indies into Australia. Since the end of hostilities some of the productive fields on Sumatra and Java have been revived. The newer fields on Borneo are also receiving attention. In addition there are small pools on Ceram and on New Guinea which foreshadow extensive operations on those islands. On the mainland oil has been found in China and in Burma. In Australia there is at present only one oil pool. Two small pools have been found in New Zealand. In the Philippine Islands seepages are known in at least 12 widely scattered areas.

The search for additional oil supplies will go forward in these far-off places during the next 50 years. Those who will do the prospecting will be interested in the stratigraphy and especially the deformational history of that part of the world.

A rather exhaustive review of the literature involving the distribution of sediments as well as their subsequent alteration by folding and faulting, would be very convenient for those who must direct the field work. Such a review is presented by H. Stille, H. Kölbel, and G. Y. Lee in the book under consideration. The introductory article gives a good summary of the facts now known about the stratigraphic sequence and the tectonic history of Korea. In the second article the outstanding facts regarding China are similarly analyzed. A striking feature brought out by Lee is the fact that a large number of the standard orogenic phases as classified by H. Stille can be documented in various parts of China. The most important are the Caledonian, late Jurassic, and late Cretaceous periods of deformation. A good bibliography is appended to this article.

The next part of the book is devoted to Burma, Thailand, the Malay Peninsula, and the many islands of the Pacific which lie between Asia and Australia. For each of these the author presents a convenient schematic tabular summary, so that the reader can quickly find the highlights of the sedimentational history. It is interesting to note that the orogenic phases vary in time and space by the usual progressional history of continents. The very early periods of folding such as the Taconic up to the Variscan are evident on the continental masses. Outward toward the ocean the Mesozoic phases become more prominent. On the fringes of the continent and on the islands, the Tertiary phases predominate. As on other continents, there is abundant evidence of numerous phases of folding during the Tertiary and even into Pleistocene time.

[1] Professor of geology, University of Wichita. Review received, June 6, 1949.

The next article in the book is devoted to the geology of Australia. Here the author had a somewhat more voluminous set of references than were available for southeastern Asia. Consequently the story is more complete. Besides describing the paleogeology in detail, the author shows that orogenic movements took place in late Cambrian, late Ordovician, late Silurian, late Devonian, and in Carboniferous time. Most of these orogenic phases are well documented in the southeastern part of the continent. In other parts of the continent there is evidence of several phases of Variscan folding and well as prominent deformation during parts of Mesozoic time. The Tertiary is marked as usual by large-scale faulting. The appended list of references should prove very valuable to those who wish to read details concerning the geology of Australia and its bordering islands.

The final article in the book is devoted to a comprehensive examination of times of folding in the lands which now border the Pacific Ocean.

RECENT PUBLICATIONS

ALGERIA

*"Contribution a l'Étude stratigraphique du Nummulitique algérien" (Contribution to the Stratigraphic Study of the Algerian Nummulitique), by Jacques Flandrin. *Service Carte Geol. Algérie Bull. 19*, 2e Ser., Stratigraphie (Alger, 1948). 340 pp., 90 figs., 8 pls. 10×13 inches. Paper cover. French.

ARGENTINA

*"Descubrimiento de Paleozoico superior en la zona extraandina de Chubut" (Upper Paleozoic in Extra-Andean Zone of Chubut), by Tomas Suero. *Y.P.F. Bol. Inform. Petrol.*, Vol. 25, No. 287 (Buenos Aires, July-December, 1948), pp. 31–48; 7 figs., 1 table.

*"Sobre la presencia del Hauterivense marino en la Sierra de Chachahuén, Provincia de Mendoza" (Marine Hauterivian [Cretaceous] in Sierra de Chachahuén, Mendoza), by Eduardo L. Paula. *Ibid.*, pp. 49–53; 3 figs.

ARKANSAS

*"Petroleum Exploration in Eastern Arkansas with Selected Well Logs," by Charles A. Renfroe. *Arkansas Div. Geology Bull. 14* (Little Rock, 1949). 159 pp., 3 pls., 2 figs., 20 tables. 6×9 inches. Cloth.

Dry-Hole Map of Southern Arkansas, Arkansas Resources and Development Commission, Division of Geology, Harold B. Foxhall, director, Little Rock. New map showing location, owner, lessor, total depth, and elevation where available on all wells; and exact location of all producing areas in the southern half of Arkansas. Prepared from the official records of the Division of Geology, Little Rock, and the Arkansas Oil and Gas Commission, El Dorado. Scale, 1 inch equals 3 miles. Prints measure 42×84 inches. Map is current to May 1, 1949, and will be issued in successive revisions every 3 months. Cloth copies available at $17.50 plus 50 cents mailing cost, and paper copies at $10.00 plus 50 cents mailing cost. Orders should be sent and checks made payable to: J. L. McDonnell, Box 144, Pulaski Heights Station, Little Rock, Arkansas.

CALIFORNIA

*"Structure of a Portion of the San Andreas Rift in Southern California," by Robert E. Wallace. *Bull. Geol. Soc. America*, Vol. 60, No. 4 (New York, April, 1949), pp. 781–806; 3 pls., 3 figs.

CANADA

"Canada's Coral Reefs Point to Big Potential," by Theodore A. Link. *Oil Forum* (New York, April, May, June, 1949). Text and illus.

COLORADO

"Stratigraphy and Geologic Structure in the Piedra River Canyon, Archuleta County, Colorado," by C. B. Reed, G. H. Wood, A. A. Wanek, and Pedro Verastegui Mackee. *U. S. Geol. Survey Prelim. Map 96*, Oil and Gas Inves. Ser. (May, 1949). Sheet 40×49 inches. Map scale, 2 inches equal 1 mile. Map Distribution Office, U. S. Geological Survey, Denver Federal Center, Denver, Colorado. Price, $0.80.

EAST INDIES

Structural History of the East Indies, by J. H. F. Umbgrove. 63 pp., 68 figs., 4 tables, 10 pls. 10×12.5 inches. Cloth. Cambridge University Press, American Branch, 51 Madison Avenue, New York (1949). Price, $4.00.

FLORIDA, GEORGIA, AND ALABAMA

*"Oil and Gas Developments in Florida, Georgia, and Alabama during 1948," by Herman Gunter. *Oil and Gas Jour.*, Vol. 48, No. 2 (Tulsa, May 19, 1949), pp. 337–42, 351; 2 figs.

FRANCE

*"Monographie Géologique du Champ Pétrolifère de Pechelbronn" (Pechelbronn Oil Field), by René Schnaebele, with contributions by J. O. Haas and C. R. Hoffmann. *Service Carte Géol. Alsace et Lorraine Mem. 7* (Strasbourg, 1948). 254 pp., 40 figs., 16 tables, 18 pls. Bibliog. of 176 titles. Paper. Approx. 8.75×10.75 inches. French.

GENERAL

*"Distribution of Mountain Building in Geologic Time," by James Gilluly. *Bull. Geol. Soc. America*, Vol. 60, No. 4 (New York, April, 1949), pp. 561–90; 16 figs.

*"State Geological Surveys," by Wilson M. Laird. *California Jour. Mines and Geology*, Vol. 45, No. 2 (San Francisco, April, 1949), pp. 299–317. Reprinted from *The American Year Book, 1948*.

**Oil Fields in North America*, by W. A. Ver Wiebe. Expanded from the author's *Oil Fields in the United States* (1930). 251 pp. 109 figs., 63 tables. 8.5×11 inches. Paper cover. Published by the author (1949). W. A. Ver Wiebe, 150 North Chautauqua, Wichita 8, Kansas. Price, $6.00.

**Geology, An Introduction to Earth-History*, by H. H. Read. No. 198 of the Home University Library of Modern Knowledge. 248 pp., 30 figs. 4.125×6.5 inches. Cloth cover, paper jacket. Oxford University Press, 114 Fifth Avenue, New York, N. Y. (1949). Price, $2.00.

**The Ocean*, by F. D. Ommanney. No. 203, *ibid.* 238 pp., 12 figs.

*"Report of the Committee on a Treatise on Marine Ecology and Paleoecology, 1947–1948," by Harry S. Ladd, chairman, *et al. Natl. Research Council Div. Geol. and Geogr. No. 8* (Washington, D. C., December, 1948). 117 pp. Paper. 8.5×11 inches. Price, $1.00.

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ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1296-1309, 1 FIG.

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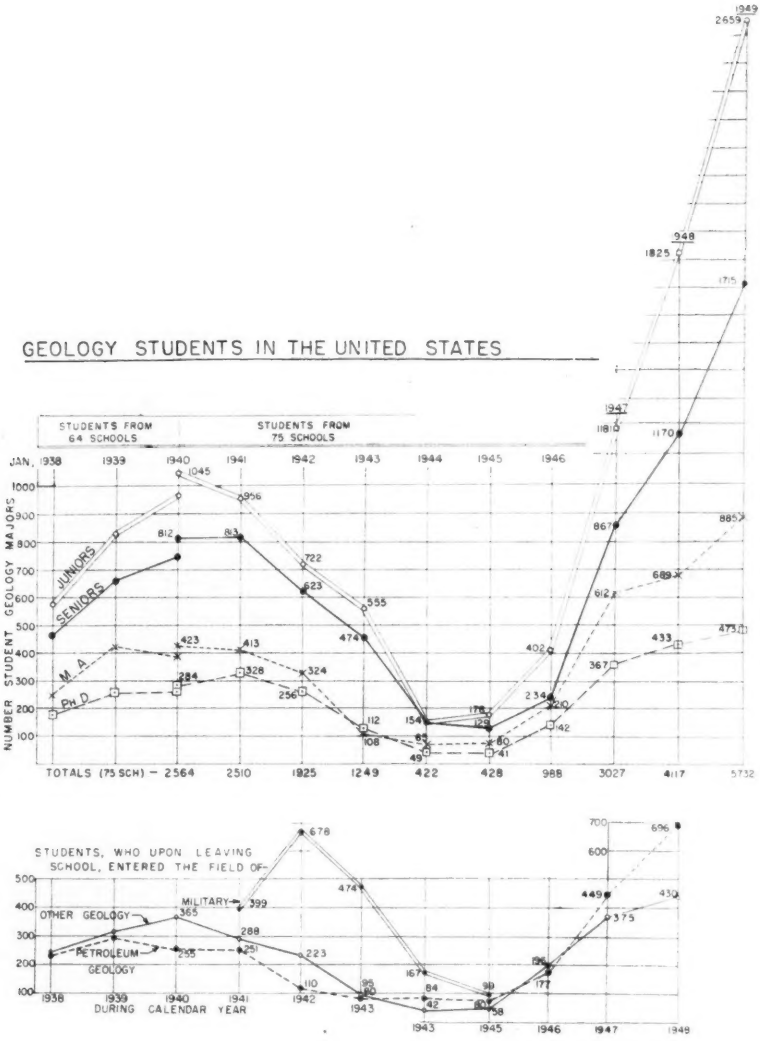
SURVEY OF COLLEGE STUDENTS MAJORING IN GEOLOGY[1]

A. I. LEVORSEN[2]
Stanford University, California

The chart is a continuation of the surveys of recent years. It shows the trend in the number of college students majoring in geology in the United States, and the placement of those leaving school during the calendar year, 1948. The latest figures are for January, 1949. In considering the chart, it should be remembered that these figures include only the enrollment in the first semester of those colleges using the two-semester system, and the enrollment for the second quarter of those colleges using the quarter system.

[1] Manuscript received, May 23, 1949.

[2] Dean of the School of Mineral Sciences.


GEOLOGY STUDENTS IN THE UNITED STATES
STUDENTS FROM 64 SCHOOLS
STUDENTS FROM 75 SCHOOLS
JAN, 1938
1939
1940
1941
1942
1943
1944
1945
1946
NUMBER STUDENT GEOLOGY MAJORS
JUNIORS
SENIORS
M.A.
PH.D
TOTALS (75 SCH) – 2564 2510 1925 1249 422 428 988 3027 4117 5732
STUDENTS, WHO UPON LEAVING SCHOOL, ENTERED THE FIELD OF-
OTHER GEOLOGY
MILITARY
PETROLEUM GEOLOGY
DURING CALENDAR YEAR
1938
1939
1940
1941
1942
1943
1945
1946
1947
1948

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Ralph James Newton, Rio Vista, Calif.
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Elton Ernest Rodgers, Jr., Lubbock, Tex.
Leroy T. Patton, Charles A. Renfroe, W. I. Robinson
David Paul Rothrock, Vermillion, S. D.
F. J. Pettijohn, Raymond D. Sloan, George R. Downs

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Ferhan Mustafa Sanlav, Istanbul, Turkey
F. M. Van Tuyl, R. C. Holmer, W. S. Levings
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Thomas B. Weaver, Wichita, Kan.
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Ross Walter Craig, Calgary, Alta., Canada
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Edward Cunningham Dillon, Houston, Tex.
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Alfred N. Sharrick, G. S. Lambert, R. E. McAdams

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Robert Paul Harder, Wichita, Kan.
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Roy P. Hardy, Wichita, Kan.
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Raymond Siever, Urbana, Ill.
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Harrison EdFred Stommel, Golden, Colo.
J. Harlan Johnson, Paul E. Nash, F. M. Van Tuyl
H. D. Teel, Wichita Falls, Tex.
Samuel P. Ellison, Jr., W. J. Lang, Russell Farmer
Richard Kent Waddell, Tulsa, Okla.
John T. Lonsdale, Hal P. Bybee, H. B. Stenzel

WORLD WAR II SERVICE RECORDS

At the recommendation of the A.A.P.G. committee on national responsibility, in order to attain its objective "to plan and advise with the Military Services for the effective application of geology and the efficient functioning of geologists within the Military Services," the executive committee is requesting each applicant for membership to return a statement of his World War II service and his present reserve status, if any, for which purpose a special blank is furnished by Association Headquarters, Box 979, Tulsa 1, Oklahoma.

AMERICAN GEOLOGICAL INSTITUTE

Appointment of DAVID M. DELO of Washington, D. C., as the first executive director of the American Geological Institute, has been announced by DETLEV W. BRONK, chairman of the National Research Council.

The American Geological Institute is a new organization established in November, 1948, which will represent the profession of geology. It is composed of a union of eleven geological societies whose members total more than 10,000 professional geologists. Headquarters will be located in the National Research Council, 2101 Constitution Avenue, Washington 25, D. C., and the activities of the Institute will be carried on in conjunction with those of the Division of Geology and Geography, NRC.

The primary objectives of the new Institute are the advancement of geology and its application to human welfare by providing a means for the cooperation of organizations active in the fields of pure and applied geology. Membership is open to all non-profit organizations concerned with the earth sciences—geology, geophysics, geochemistry, mineralogy, *et cetera*. The initial member organizations are:

American Association of Petroleum Geologists
American Geophysical Union
American Institute of Mining and Metallurgical Engineers
Geological Society of America
Mineralogical Society of America
Paleontological Society
Seismological Society of America
Society of Economic Geologists
Society of Economic Paleontologists and Mineralogists
Society of Exploration Geophysicists
Society of Vertebrate Paleontology

The Institute is organized as an instrument of the National Research Council, in this way uniting geologists with all other American scientists who are seeking solutions to problems which can be attacked best through group or united action. Initially its functions will be concerned primarily with the non-research activities of the geological profession, and will supplement the work of the Division of Geology and Geography of the National Research Council which is chiefly concerned with the coordination of research in geology and geography and its interrelationships with allied sciences.

Officers of the Institute are A. I. LEVORSEN, Dean of Mineral Sciences, Stanford University, president; W. B. HEROY, Beers and Heroy, Dallas, Texas, vice-president; and EARL INGERSON, U. S. Geological Survey, Washington, D. C., secretary-treasurer.

Delo began his duties on June 1. He has served for the past 3 years as chief of Scientific Manpower for the Research and Development Group, Logistics Division, General Staff, United States Army. During the World War II he was a technical aide in the Office of Scientific Research and Development and prior to that time was chairman of the Department of Geology and Geography, Knox College.

The new executive director is a graduate of Miami University (Ohio) and received his doctorate degree from Harvard University. He is a Fellow of the Geological Society of America and a member of Phi Beta Kappa and Sigma Xi.

NOMINATING COMMITTEE

The executive committee has appointed the following members of the nominating committee. EARL B. NOBLE, chairman, Los Angeles, California; MONROE G. CHENEY, Coleman, Texas; CHARLES J. HARES, Boulder, Colorado; LYNN K. LEE, Chicago, Illinois; W. C. SPOONER, Shreveport, Louisiana.

Pertinent excerpts from the by-laws and the constitution are here quoted.

BY-LAWS. *Committees, Article VI. Nominating committee, Section 14.*—The purpose of the nominating committee is to nominate candidates for the Association offices as provided in the constitution. The committee shall consist of a chairman and four other members appointed by the executive committee to serve one year. At least two members of the nominating committees shall be past officers of the Association.

CONSTITUTION. *Officers and their duties, Article IV. Officers, Section 1.*—The officers of the Association shall be a president, a vice-president, a secretary-treasurer, and an editor. These, together with the past-president, shall constitute the executive committee and managers of the Association.

Section 2.—The officers shall be elected annually from the Association at large by secret mailed ballot in the following manner. The nominating committee shall nominate one or more candidates for each office, and its nominations shall be published in the September *Bulletin*. Additional nominations may be made by written petition of fifty, or more, members in

good standing received at Association headquarters not later than November 15. The executive committee shall then prepare a printed ballot, listing the candidates for each office, and one ballot shall be mailed to each member as soon after November 15 as possible. Ballots returned to Association headquarters on or before January 31 shall be placed as received in a locked ballot box and promptly after January 31 the ballot committee shall open the ballot box and count the ballots. Ballots of delinquent members shall not be counted. A majority of all votes cast for an office is necessary for election. If there are three or more nominees for any office, a preferential form of ballot shall be used. In case of a tie vote, the executive committee shall cast one additional deciding vote. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as a candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidates for the executive committee for two years.

Section 3.—No one shall hold the office of president for two consecutive years and no one shall hold any other office for more than two consecutive years except the editor who shall not hold office for more than six consecutive years.

A.A.P.G. REGIONAL MEETING, BILOXI, MISSISSIPPI OCTOBER 12–14, 1949

A regional meeting of the Association will be held at the Buena Vista Hotel, Biloxi, Mississippi, October 12–14, 1949. The following six southeastern geological societies are the co-hosts: East Texas, Mississippi, New Orleans, South Louisiana, Shreveport, and Southeastern.

Several geophysical papers of interest to the geologists will be presented by the Ark-La-Tex Geophysical Society.

Hotel-room reservation cards will soon be mailed to all members and an early reply will be appreciated by the committee.

Tentatively, the program consists of a pre-convention symposium on the work in the Gulf Coast of the Cenozoic and Mesozoic subcommittees of the geologic names and correlations committee. The technical program will be shared equally by the participating geological societies. Each group will present papers dealing with significant problems of their areas.

A series of air-borne excursions over the Mississippi Delta and including aerial visits to the water operations are contemplated.

The convention committee for this meeting consists of the following.

Chairman: T. H. PHILPOTT, The Carter Oil Company, Box 1739, Shreveport, Louisiana.
Hotels: M. N. BROUGHTON, The Texas Company, Box 252, New Orleans, Louisiana.
Publication: L. R. MCFARLAND, Magnolia Petroleum Company, 508 Millsaps Building, Jackson, Mississippi.
Publicity: HASTINGS MOORE, Danciger Oil and Refining Company, 207 Webster Walk, Henderson, Texas.
Technical equipment: G. E. MURRAY, Louisiana State University, Baton Rouge, Louisiana.
B. M. CHOATE, Atlantic Refining Company, Jackson, Mississippi.
F. M. SCHALL, Big Chief Drilling Company, Shreveport, Louisiana.
W. B. NEILL, Stanolind Oil and Gas Company, Lake Charles, Louisiana.
J. L. MARTIN, JR., Sinclair-Wyoming Oil Company, Jackson, Mississippi.
Geophysical papers: H. M. BUCHNER, The Carter Oil Company, Drawer 1739, Shreveport, Louisiana.
L. F. FISCHER, Sohio Petroleum Company, Shreveport, Louisiana.
G. E. WAGONER, The Carter Oil Company, Box 1739, Shreveport, Louisiana.
Field excursions: D. E. NEWLAND, Magnolia Petroleum Company, Box 872, Lake Charles, Louisiana.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 7 (JULY, 1949), PP. 1311–1316, 3 FIGS.

MEMORIAL

WALTER STALDER

(1881–1949)

Walter Stalder, familiarly known to many of his friends as "Cap," died at his home in Oakland, March 16, 1949. He was a member of an early-day Oakland family and resided for his entire life in the home in which he was born.

"Cap" was born in Oakland, California, April 6, 1881. He attended the University of California; he majored in chemistry and graduated in 1904 with a degree of B.S. He served as a chemist for the San Francisco Chemical Company for the next two or three years and then returned to the University and obtained the Master of Science degree, majoring in geology.

As a petroleum geologist, he worked with M. L. Requa and the Nevada Petroleum Company from 1909 until 1911. In that year he joined the Union Oil Company of California to do land valuation work and it was at this time that the fundamentals of the present decline-curve method of estimating oil reserves originated. He served again with the Nevada Petroleum Company from 1911 to 1913, and then as chief geologist on valuation for Independent Oil Producers, 1914 to 1915. From 1916 until his death he was in the consulting practice. It was he who recommended and brought in the Marysville Buttes gas field, the first real commercial discovery of gas in Northern California.

Stalder was a member of the A.A.P.G., the American Chemical Society, the Seismological Society of America, the California Academy of Sciences, and the American Association for the Advancement of Science. He was a very active member of the American Institute of Mining and Metallurgical Engineers, serving as chairman of the San Francisco section in 1945.

"Cap" Stalder was an energetic hard worker endowed with a contagious enthusiasm to carry forward those things in which he believed. He was a man of broad and well rounded experience who would freely and unstintingly impart his knowledge to those who sought it. He liked people; had a host of friends and is sincerely missed, particularly in the San Francisco district, by members of the American Institute of Mining and Metallurgical Engineers and the American Association of Petroleum Geologists.

G. C. GESTER

San Francisco, California
April 29, 1949

JAMES ARTHUR WILSEY, JR.

(1921–1949)

James Arthur Wilsey, Jr., son of James A. and Lucy Hill Wellwood Wilsey, was born on November 3, 1921, at Englewood, New Jersey. After early schooling in Englewood, at Indian River, Florida, and at Hun School, he graduated from St. Paul's School, Concord, New Hampshire, in 1939, *cum laude*, with honors in mathematics. In the autumn of 1939 he entered Princeton University, and after commencing his sophomore year he married Miss Caroline Williams of Haverford, Pennsylvania. Following his marriage he withdrew from Princeton University and entered the University of Texas in January, 1941, where he received a B.S. degree with high honors in February, 1943.

From February, 1943, until October, 1944, he did exploratory work in the Wind River region of Wyoming for the Carter Oil Company. On October 27, 1944, he entered the

United States Army, and was placed in the Corps of Engineers and trained in aerial photography at Fort Belvoir, Virginia. Following his training, he became a technical sergeant attached to "A" Headquarters Company, AFMIDPAC, and was stationed in Hawaii, where he was engaged in "beach intelligence."

Following the close of the war he was released from the Army on June 21, 1946, and admitted to the Princeton Graduate School in September, where he commenced advanced work in the department of geology. During the academic years 1946–1947 and 1947–1948,

JAMES ARTHUR WILSEY, JR.

he made an outstanding record, both as a graduate student and as an assistant in instruction. He received his A.M. degree in June, 1948, after having made a rating of "Excellent" on his general examinations. He was a candidate for a Ph.D. degree in June, 1949.

Particularly because of his personal familiarity with, and interest in, the mountain regions of southwestern Montana, Jim undertook as his thesis work the study of a critical and complex area in the Taylor's Fork drainage of the Gallatin Valley, northwest of Yellowstone Park. His field work during the summers of 1947 and 1948 was financed by the Phillips Petroleum Company, for whom he made a general reconnaissance survey of the entire Gallatin Valley structural province. During the autumn of 1948 he completed a report of the descriptive geology and oil possibilities of this area, in the company's offices in Denver.

Returning to Princeton shortly before Christmas, 1948, Jim was stricken with poliomyelitis on December 29, and passed away at the Sister Kenney Hospital in Jersey City, New Jersey, on January 10, 1949. He is survived by his wife and two children (David Lynn and Lucretia); his mother and father; a brother (Dr. John D. Wilsey); and three sisters (Miss Elizabeth Wilsey, Mrs. Lindley Hoag, and Mrs. Chester Lloyd-Jones).

He was a member of Sigma Gamma Epsilon, Sigma Xi, the American Association of Petroleum Geologists, and the Geological Society of America.

Jim Wilsey was an outstanding student, a scientist of demonstrated ability and exceptionally great promise, a warm and generous friend, and a modest and kind gentleman. He was respected and admired by all within his circle of acquaintance, and his memory will provide an example and a source of inspiration to all who knew him.

W. T. THOM, JR.
ALEX W. MCCOY, III

Princeton, New Jersey, and
Denver, Colorado
April 29, 1949

CECIL DRAKE

(1899–1949)

Cecil Drake's heart failed him on January 31, 1949, at Taft, California, and the few of us who knew him well will miss his charmingly shy personality, wise counsel and good fellowship. "Ducky," as he was best known, had few intimate friends but those who were permitted to be so counted feel honored by that rare privilege.

"Ducky" was only 49 years old when he died and had been exceptionally active until a year ago when his heart first gave signs of weakness. He was born, June 3, 1899, at Lyons, Rice County, Kansas, the younger of two sons of S. B. Drake and Nina Mathews Drake. His parents were pioneers of the Midwest.

He obtained his early schooling in Lyons and graduated from high school at that place in 1918. He was too young to join the United States armed forces of the first world war, but became a member of the R. O. T. C. when he entered Colorado School of Mines in September, 1918. He was a good student and graduated in June, 1922, with the degree of Engineer of Mines. He was small of stature but had a stout heart in his college days; he boxed in the feather-weight class, at 105 pounds. He was a member of Beta Phi Chapter of Beta Theta Pi and very active in fraternity affairs. He was my room-mate at "Mines," where there began a life-long friendship as close as blood brothers. He joined the Golden City Lodge No. 1 of the Masonic Order on March 13, 1922.

Upon graduation from college, "Ducky" was employed briefly at Taft, California, but in September, 1922, he joined the geological staff of the Shell Oil Company's former Mexican subsidiary, Cia. Mexicana de Pet. "El Aguila," as field geologist. In 1926 he was placed in charge of El Aguila's subsurface department where he carried on the geological correlation and petroleum engineering practices pioneered by John Muir, whom he succeeded. The subsurface department was eventually absorbed by the petroleum engineering department but he remained in the geological department to work on special subsurface problems until the properties of El Aguila were expropriated in March, 1938. Thereafter he spent 1½ years on an extensive leasing venture in Nebraska. In September, 1939, he rejoined the Shell Oil Company in Centralia, Illinois, as a petroleum engineer and was transferred in that capacity to the Tulsa, Oklahoma, office in September, 1943.

"Ducky" inherited considerable land in the Kansas wheat belt and left the Shell Oil Company early in 1944 in order better to organize his land holdings. He married Florence Dubbs of Tulsa in December, 1945, and is survived by his wife.

CECIL DRAKE

The oil business was so much a part of his life that he could not remain out of it and in March, 1946, he joined the petroleum engineering staff of the Standard Oil Company of California. He was stationed in Taft, California, and it was here that "Ducky" started and ended his professional career.

G. F. KAUFMANN

Tokyo, Japan
March 26, 1949

ROBERT HASTINGS PALMER

(1882–1948)

Robert Hastings Palmer died at Bay Pines, Florida, on May 14, 1948. The official cause of his death was pneumonia, but those of us who knew him best, realized that the actual cause was the death of his wife Dorothy a few months before, as without her life was not worth while.

Dr. Palmer was born on a farm near Toledo, Ohio, on December 1, 1882, the son of Wesley and Sally Ward Palmer. At an early age he moved to Palmyra, Michigan, to live with his uncle, Robert Hastings. He attended the Michigan public schools and college in Adrian, Michigan, where he received an A.B. degree in 1906. After a short period of teaching school in North Dakota and Utah, he returned to school and received an M.A. from the University of Utah in 1909, and a J.D. from the University of Chicago in 1912.

While practicing law in Pocatello, Idaho, he first became interested in the sciences of geology and paleontology. His mind was always in the field and after five years of law practice, he realized that his greatest interest lay in the natural sciences. The break came with the World War, during which period he was a lieutenant in the Army and after discharge he entered the Stanford University to study geology.

After receiving his degree from Stanford in 1920, he was assistant professor in geology and paleontology at the University of Washington, and in 1921 he proceeded to Mexico to become the chief stratigrapher and paleontologist with the Instituto Geologico de Mexico. In 1923 he returned from Mexico and married Dorothy Kemper, a micropaleontologist in San Antonio, Texas. From that time on his life was one of devotion to Dorothy and his natural sciences, primarily paleontology. For a short period they lived in La Jolla, California, then returned to Stanford University where he received his Doctor's degree in 1926.

His professional work as geologist and paleontologist carried him to the state of Washington during 1926 and 1927; to Colombia, for the Gulf Oil Company in 1928, and to Cuba for the Atlantic Refining Company from 1929 through 1931. Thereafter his home was in Habana, Cuba, where he set up a consulting office and continued his scientific studies until his death.

Dr. Palmer was renowned not only for his paleontologic studies but for the other branches of biology and ornithology. He travelled widely over the Island of Cuba and was known as the outstanding authority on birds of the Northern Caribbean Islands. His home was the mecca of travelling scientists, and no trip to Cuba was ever complete without a visit to his laboratories and home.

His professional career was replete with publications, some of which are still guides to the geology and paleontology of Cuba. To him and his wife must go full credit for the establishment of the stratigraphic section of the Island of Cuba. His last paper, an outline of the geology of Cuba, was published by the *Journal of Geology* in 1945. Several years were spent on the preparation of a paper entitled "Echinoids of Cuba," for which he had received the approval of a grant from the Geological Society of America. Specimens for the paper had been selected and photographed and the first draft had been prepared at the time of his death. The work will be completed by Dr. Wyatt Durham.

Dr. Palmer was a member of the American Association of Petroleum Geologists, the Geological Society of France, the Society of Sigma Xi, the Cooper Ornithological Club, the Pacific Northwest Bird and Mammal Society, the Geological Society of America, and was a fellow of the American Association of Advancement of Science, and of the "Sociedad Cubana de Historia Natural."

No memorial of Robert Palmer could be complete without the mention of his wife, Dorothy K. Palmer. These two people so complemented each other that one thought of them as a team rather than separate individuals. They were more than prominent geologists and paleontologists, as their interest embraced all nature. Their collections included marine, botanical, and ornithological specimens as well as extensive fossil collections. Their idea of a vacation was to go on a field collecting trip.

The Palmers had open house to all visiting geologists who passed through Habana. Their host of friends embraced people in many walks of life. Dorothy Palmer preceded Bob in death, and with her passing he felt he had little to live for and it seemed he was an-

xious to again join her in another world, where outcrops of many ages would be abundant and prolific with forams and echinoids. All who knew the Palmers will miss these fine people.

HOWARD M. KIRK

Guatemala City, Guatemala
June 1, 1949

THOMAS KNIGHT KNOX

(1896–1949)

The untimely death, March 7, 1949, of Thomas Knight Knox from a heart ailment closed an active and useful career for a geologist and petroleum engineer who leaves behind a host of warm friends in the Southwest. "T. K." was born at Anniston, Alabama, March 4, 1896. He studied civil engineering at the A. & M. College of Texas in 1917 and geology at Louisiana State University in 1925 and at the University of Texas in 1926.

T. K. had a wide experience in the oil industry that included: two years (1919–1921) as a drilling contractor and oil producer in Louisiana and Texas; four years (1921–1925) as superintendent of production for Gas-Products Company; one year (1925–1926) assistant to chief consulting engineer, P. M. Biddison, Gas-Products Company, Ruston, Louisiana; nine years (1926–1935) as a valuation and appraisal engineer associated with P. M. Biddison and Texla Royalty Company, Dallas, Texas. He was named chief geologist of the Republic Natural Gas Company when it was organized in 1935 and advanced to vice-president, which position he held when he retired in 1947 because of ill health.

Knox was elected to membership in the Association in 1929. He was also a member of the American Institute of Mining and Metallurgical Engineers, American Petroleum Institute, past secretary-treasurer of the Dallas Geological Society, and was a charter member of the Petroleum Engineers Club of Dallas. He was a Knight Templar and a member of the Highland Park Presbyterian Church in Dallas.

T. K. was a man of high moral principle who was devoted to his family and profession, and was thoughtful and unselfish in dealings with his fellow man. His gratitude for the smallest assistance was always promptly expressed, and he stood ready to lend aid whenever he could. He made a special trip to Corpus Christi to Dallas in 1937 to discuss a paper presented by the writer, and his discussion was more effective than the paper. The absence of T. K. Knox with his kind and gentle disposition will be felt deeply by his friends and professional colleagues.

Knox is survived by his wife, a son, Thomas, both of Dallas, and two daughters, Mrs. H. B. McLendon of Midland, Texas, and Mrs. Fred M. Wilber of Dallas.

CHARLES B. CARPENTER

Dallas, Texas
June 9, 1949

DONALD KELLY

(1898–1949)

Donald Kelly was born in Lincoln, Nebraska, March 8, 1898, the son of Daniel Kelly and Mary Brown Kelly. He died of a heart attack at Wichita Falls, Texas, June 1, 1949, leaving his wife, Jeanette Kelly, of Wichita Falls, Texas, a daughter, Marcia Kelly of Rochester, Minnesota, a son, Robert Kelly, a student at the University of Nebraska, and a brother, Jay E. Kelly of Lincoln, Nebraska. Donald was married to Jeanette Bagnell, August 30, 1923, at Glendale, California.

Donald attended the Lincoln grade and high schools until the first World War when he entered the army and spent considerable time in France. Upon his return he entered

the University of Nebraska where he completed his high-school work and graduated with the degree of Bachelor of Science in 1924. In school he was a member of the Acacia fraternity and a member of Sigma Gamma Epsilon. He became a member of the American Association of Petroleum Geologists in 1924 and continued his membership until his death. He was president of the North Texas Geological Society for the 1944–1945 term. He

DONALD KELLY

also was a member of the Masonic Lodge in Lincoln and a member of the Maskat Shrine Temple and Presbyterian Church in Wichita Falls.

His first work was with the Empire Gas and Fuel Company at Bartlesville, Oklahoma. Later he joined the geological staff of the Marland Oil Company in Denver, Colorado, where he did extensive field work in the Rocky Mountain area. In 1926 he came to Texas with the same company to do field work here. In 1927 the Marland Oil Company retrenched and Donald found himself out of work. He soon joined The Texas Company and for two years did surface field work in the North Texas area. In 1929 he moved to Wichita Falls. Somewhat later he was elevated to the position of district geologist for the North Texas division of The Texas Company, in which position he remained until September, 1948, when he resigned and entered the oil business as a consulting geologist.

Donald was a pioneer in the study of petroleum geology. He attained a reputation for himself as being one of the best surface geologists in the profession. As a corporation geologist he adhered strictly to the policies of his employer and to the ethics of his profession, ever loyal to his high ideals and true to his convictions. He was a devoted husband, a kind and loving father, and a highly respected citizen in his community, and above all a true friend. He will be greatly missed by all who had the good fortune to know him either professionally or otherwise.

FRED K. FOSTER

Abilene, Texas
June 13, 1949

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VOL. 33, NO 7 (JULY, 1949), PP. 1317-1318

AT HOME AND ABROAD

NEWS OF THE PROFESSION

DIRECTORY OF FILMS AND SLIDES

Copies of the booklet entitled *Directory of Films and Slides of Possible Interest to Geologists*, prepared by HELGE E. HANSEN, Audio-Visual Education Center, University of Michigan, Ann Arbor, and KENNETH K. LANDES, who was chairman of the A.A.P.G. committee on applications of geology, 1947–1948, are available, *gratis*, upon request directed to A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma. This is a 22-page, lithoprinted, $8\frac{1}{2} \times 11$-inch paper-covered publication.

C. M. LINEHAN is district geologist for the Kewanee Oil Company at Midland, Texas. He was recently with the Superior Oil Company.

HARRY JAY WERNER has left the Washington University at St. Louis, Missouri; he may be addressed in care of the Virginia Geological Survey, Charlottesville, Virginia.

JOHN C. MICHELSON, recently at the State University of Iowa, Iowa City, is in the department of geology at the State College of Washington, Pullman, Washington.

ROBERT VAN VLECK ANDERSON, Stanford University, died on June 6 at the age of 65 years. He recently returned from a series of studies in the Sahara Desert.

W. VAN HOLST PELLEKAAN, independent geologist of Beverly Hills, California, died on June 7, at the age of 68 years. He was for years the chief geologist of the Shell Company of California.

The Houston Geological Society annual student awards this year were won by WILLIAM P. RYMAN, of the geology department of Texas A. and M. College, College Station, for his paper "Origin of the Calcite Zone in Salt-Dome Cap Rock," and N. A. PRINCE, of the petroleum engineering department, for his paper "Cycling Versus Pressure Depletion." The Houston society pays the associate membership dues of the winners for 2 years in the A.A.P.G. Presentation of the papers in oral competition was made at a dinner meeting of the Society on May 9. Other competitors were WILLIAM N. MOSELEY, "The Use of Geophysics in the Study of Configuration of Salt Domes," and H. V. RISIEN, "Determination and Significance of Interstitial Water in Oil Production." The welcoming address was delivered by ALEXANDER DEUSSEN and the judges were A. L. SELIG, WILLIAM C. KNEALE, PHILIP A. JENNINGS, WAYNE V. JONES, and RUSSELL WEINGARTNER.

The following members of the Shawnee Geological Society are the newly elected officers for 1949–1950: president, DOYLE M. BURKE, The Texas Company; vice-president, JACK W. DAVIES, Halliburton Oil Well Cementing Company; secretary-treasurer (re-elected), Miss MARCELLE MOUSLEY, Atlantic Refining Company, Box 169, Shawnee, Oklahoma. The Society meets the third Thursday of each month at 8 P.M. at the Aldridge Hotel, Shawnee. Visiting geologists are welcome.

BLAKEMORE E. THOMAS, of the California Institute of Technology, has been appointed assistant professor of geology at the University of Kansas, to teach petrography and economic geology.

ROBERT A. HARRIS has resigned from the United States Geological Survey to accept a position as geologist with the Atlantic Refining Company at Shreveport, Louisiana.

CHARLES C. BAJZA, formerly at Indiana University, is assistant professor of geology at Texas College of Arts and Industries, Kingsville, Texas.

STEWART H. FOLK has resigned his position at Baylor University to accept an assignment with DeGolyer and MacNaughton, consulting geologists and engineers, as their representative in Mexico.

DONALD KELLY, independent geologist of Wichita Falls, Texas, died of a heart attack June 1, at the age of 51 years. He was a member of the Association since 1924.

EDWIN P. WILLIAMS has left the Geological Survey of Canada to enter the employ of the Hudson's Bay Oil and Gas Company, Calgary, Alberta.

WILLIAM C. IMBT, Stanolind Oil and Gas Company, talked on "Occurrence of Oil and Gas in the Arbuckle and Ellenburger Formations," at the meeting of the Houston Geological Society, June 13.

WILLIAM HOOVER, district geologist for the Humble Oil and Refining Company in Albuquerque, represented the Association at the inauguration of TOM L. POPEJOY, ninth president of the University of New Mexico, on June 4, in Albuquerque.

The program of the meeting of the Geological Forum of the Pacific Section of the Association at Los Angeles, June 20, included talks on the "Principles of Reservoir Performance," by STUART E. BUCKLEY who is in charge of production research with the Humble Oil and Refining Company, and "Petroleum Exploration in the Arctic," by HERBERT HOOVER, JR., of the United Geophysical Company.

WILLIAM J. MCPHERSON, recently at the School of Mineral Sciences, Stanford University, is with the Imperial Oil Limited, Calgary, Alberta.

L. E. SCHLATTER has left The Hague. His address is the Anglo Egyptian Oilfields, Ltd., Box 228, Cairo, Egypt.

GEORGE CLARK GESTER retired from active work with the Standard Oil Company of California on July 1 after serving the company 32 years. He is a former president of the Association and was elected to honorary membership this year. His home address is 2725 Claremont Boulevard, Berkeley, California.

PAUL T. WALTON, who recently returned from Saudi Arabia where he negotiated an oil concession with King Ibn Saud on the Saudi Arabian-Kuwait Neutral Zone for the Pacific Western Oil Corporation, has left that company to enter into a partnership with N. G. Morgan, Sr., and N. G. Morgan, Jr., of Salt Lake City. The new firm will be known as Morgan and Walton Oils and will be headquartered at 518 Wasatch Oil Building, Salt Lake City, Utah.

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Specialist in Photogeology
Box 294
CASPER, WYOMING

Source Data

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By

J. V. HOWELL AND A. I. LEVORSEN
Tulsa, Oklahoma, and Stanford University, California

I. General Material:—National and continental in area
- A. Publications and non-commercial publishing agencies, regional, national, and continental
- B. Bibliographies, general
- C. Dictionaries, glossaries, encyclopedias, statistics, handbooks
- D. Miscellaneous books and publications of general geological interest
- E. Commercial map publishers
- F. Regional and national geologic and physiographic maps
- G. State and Province geological maps
- H. Trade journals: oil, gas, mineral industry
- I. Libraries furnishing photostat and microfilm service
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II. Specific Material:—State and Province in area
- A. Canada, by provinces
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- C. Mexico
- D. United States—states and territories

Originally published as Part II of the August, 1946, Bulletin

PRICE, 75¢ POSTPAID

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 979, TULSA 1, OKLAHOMA, U.S.A.

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4549 Produce Plaza West, Los Angeles 11

Secretary-Treasurer - - - - - Harold E. Rader
Standard Oil Company, Box 2437, Terminal Annex
Los Angeles 54

Monthly meetings. Visiting geologists are welcome.

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Vice-President - - - - - - Floyd L. Johnson
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Secretary-Treasurer - - - Maxwell G. Caben
Seaboard Oil Company of Delaware, Box 7

Dinner meetings on 2d Tuesday of each month or as announced, El Tejon Hotel, Bakersfield.

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Superior Oil Company of California
506 First National Bank Building

Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

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TALLAHASSEE, FLORIDA

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Secretary-Treasurer - - - - - Albert A. Raasch
Humble Oil and Refining Company,
Box 506

Meetings will be announced. Visiting geologists and friends are welcome.

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ILLINOIS GEOLOGICAL SOCIETY

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C. E. Brehm Drilling & Producing
Mt. Vernon

Vice-President - - - - - - - - Joseph Neely
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Box 535, Mt. Vernon

Secretary-Treasurer - - - - - Lloyd A. Harris
Carter Oil Company, Box 568, Mattoon

Meetings will be announced.

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Secretary-Treasurer - - - - - D. G. Sutton
Sun Oil Company, Box 717

Meetings will be announced.

KANSAS

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President - - - - - - - - Don W. Payne
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Vice-President - - - - - - - T. G. Wright
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - Victor F. Reiserer
Superior Oil Company, 510 K.F.H. Bldg.

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, and the Kansas Well Sample Bureau, 508 East Murdock. Visiting geologists and friends welcome.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY

NEW ORLEANS, LOUISIANA

President - - - - - - - - - Fred S. Goerner
California Company, 1818 Canal Building
Vice-President and Program Chairman - - - - - - - - - - - - M. N. Broughton
The Texas Company, 1500 Canal Building
Secretary-Treasurer - - - - - H. A. Nystrom
Schlumberger Well Surveying Corporation
452 Canal Building

Meets the first Monday of every month, October-May, inclusive, 12 noon, St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY

LAKE CHARLES, LOUISIANA

President - - - - - - - - - - W. B. Neill
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Vice-President - - - - - - - Pete Haberstick
Atlantic Refining Company
Secretary - - - - - - - - James M. Whatley
Union Sulphur Company, Sulphur, La.
Treasurer - - - - - - - - - Bert C. Timm
Magnolia Petroleum Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY

BOX 2253, WEST JACKSON, MISSISSIPPI

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Consultant, Box 2571, West Jackson
Vice-President - - - - - - - Charles E. Buck
Skelly Oil Company, 100 East Pearl Building
Treasurer - - - - - - - - - W. H. Knight
Union Producing Company
Secretary - - - - - - - - - F. T. Holden
Carter Oil Company, Box 1490

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., the Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

THE SHREVEPORT GEOLOGICAL SOCIETY

SHREVEPORT, LOUISIANA

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Vice-President - - - - - - - R. T. Wade
Schlumberger Well Surveying Corporation
Box 92
Secretary-Treasurer - - - - Charles A. Hickox
Centenary College

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

MOUNT PLEASANT, MICHIGAN

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Vice-President - - - - - Manley Osgood, Jr.
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Secretary-Treasurer - - - - - Jack Mortenson
Sohio Oil Company, 601 S. Main St.
Business Manager - - - Kenneth G. Walsworth
Dept. Conservation, Box 176

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M. Papers follow dinner. Visitors welcome.

NEW YORK

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NEW YORK, NEW YORK

President - - - - - - - - Hollis D. Hedberg
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Department of Geology, Columbia University
Secretary - - - - - - - Godfrey F. Kaufmann
Standard-Vacuum Oil Co., 26 Broadway, Room 1556

Meetings by announcement to members. Visiting geologists and friends cordially invited.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY

ARDMORE, OKLAHOMA

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Vice-President - - - - - - Earl Westmoreland
Seaboard Oil Company
Secretary-Treasurer - - - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

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Vice-President - - - - - Richard L. Roberts
Vickers Petroleum Company
Secretary - - - - - - - - - L. W. Curtis
Sohio Petroleum Company
Treasurer - - - - - - - - - Joseph M. Sears
Independent

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

OKLAHOMA

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

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The Texas Company, Box 1007

Vice-President - - - - - - - Jack W. Davies
Halliburton Oil Well Cementing Company

Secretary-Treasurer - - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the third Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

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Amerada Petroleum Corporation, Box 2040
1st Vice-President - - - - - W. Reese Dillard
Consultant, Box 2204
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Editor - - - - - - - - - - John C. Maher
U. S. Geological Survey, Federal Building
Business Manager - - - - - - - V. L. Frost
Ohio Oil Company, Thompson Building
Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Lorton Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL SOCIETY
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Box 2038
Secretary - - - - - - - - - James C. Patton
Equitable Gas Company
610 Wood St.
Treasurer - - - - - - - - - Sidney S. Galpin
Peoples Natural Gas Company
545 William Penn Place
Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

ABILENE GEOLOGICAL SOCIETY
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Vice-President - - - - - David M. Grubbs
Drilling and Exploration Company

Secretary-Treasurer - - - - - C. S. Noland
Skelly Oil Company

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

TEXAS

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Humble Oil and Refining Company Box 1271
Vice-President - - - - Norman D. Thomas
Pure Oil Company
Secretary-Treasurer - - - - - James D. Burke
Seaboard Oil Company of Delaware, Box 601

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

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Vice-President - - - - - - - H. V. Tygrett
The Atlantic Refining Company
P.O. Box 2819
Secretary-Treasurer - - - - Gilbert P. Moore
Consulting, 501 Continental Building
Executive Committee - - - - - Edgar Kraus
Atlantic Refining Company
Box 2819

Meetings: Monthly luncheons and night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
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Stanolind Oil and Gas Company
Box 660
Vice-President - - - - - R. M. Trowbridge
Consultant, 225 Owen Building
Secretary-Treasurer - - - - - Rosella L. Bunch
Shell Oil Company, Inc., Box 2037

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - F. H. Schouten
Stanolind Oil and Gas Company
Box 1410
Vice-President - - - - - - - H. C. Vanderpool
Texas Pacific Coal and Oil Company
Box 2110
Secretary-Treasurer - - - - - Thomas Nichols
Rowan Oil Company
Commercial Standard Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

TEXAS

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - Hershal C. Ferguson
Consultant, 935 Mellie Esperson Building
Vice-President - - - - - - - - - R. R. Rieke
Schlumberger Well Surveying Corporation
Secretary - - - - - - - - - James H. McGuirt
Tide Water Associated Oil Company
Treasurer - - - - - - - - - - Marjorie Fuqua
Humble Oil and Refining Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

PANHANDLE GEOLOGICAL SOCIETY
AMARILLO, TEXAS

President - - - - - - - - - G. E. Hatton
Phillips Petroleum Company, Box 1761
Vice-President - - - - - - - Robert F. Herron
Oil Development Company, 900 Polk St.
Secretary-Treasurer - - - - - - Robert B. Totten
Sun Oil Company, Box 46

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

TEXAS

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS
Box 1595

President - - - - - - - - - W. T. Schneider
Honolulu Oil Corporation, Box 1391
Vice-President - - - - - - Ralph D. Chambers
Continental Oil Company, Box 431
Secretary - - - - - - - - - - Jesse A. Rogers
The Texas Company, Box 1270
Treasurer - - - - - - - - John V. Norman, Jr.
Forest Oil Corporation, Box 1821

Meetings will be announced.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P.O. Box 545

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Gulf Oil Corporation, Box 1971
1st Vice-President - - - - Emmett E. Schieck
Morton Oil Company, Box 1970
2d Vice-President (Programs) - Donald E. Edstrom
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Secretary - - - - - - - - J. B. Headley, Jr.
Atlantic Refining Company
Treasurer - - - - - - - - - George L. Goodin
Petroleum Information, Inc.

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special meetings by announcement.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - Joseph W. McDonald
Shell Oil Company, Inc., Box 2010
Vice-President - - - - - Ralph H. McKinlay
Panhandle Producing and Refining Company
Box 1191
Secretary-Treasurer - - - - Walter L. Ammon
Stanolind Oil and Gas Company
Box 1680

Meetings: Luncheon 1st and 3d Thursdays of each month, 12:00 noon, Texas Room, Holt Hotel. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - - - Paul B. Hinyard
Shell Oil Company
2000 Alamo National Building
Vice-President - - - - - - - - J. Boyd Best
Ohio Oil Company
Secretary-Treasurer - - - Louis H. Haring, Jr.
Stanolind Oil and Gas Company

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST VIRGINIA

APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P.O. Box 2605

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United Fuel Gas Company, Box 1273
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Southeastern Gas Corp., Charleston, W.Va.
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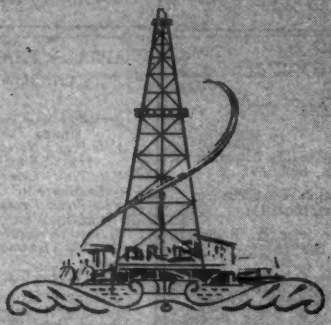

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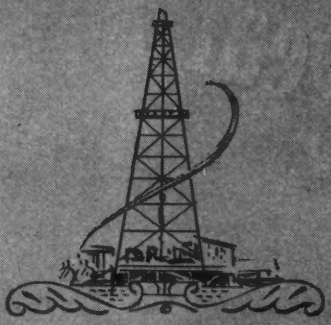

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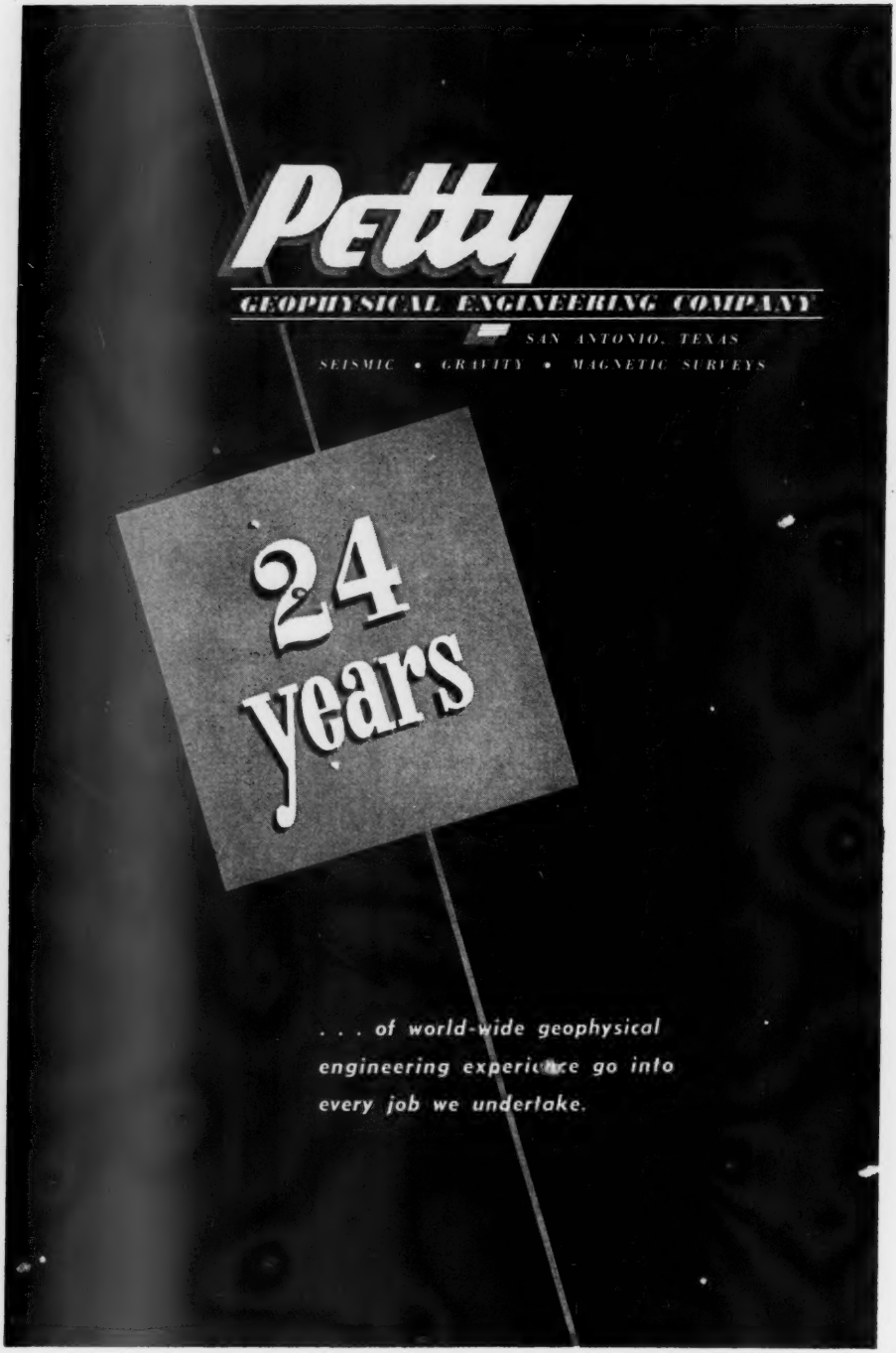
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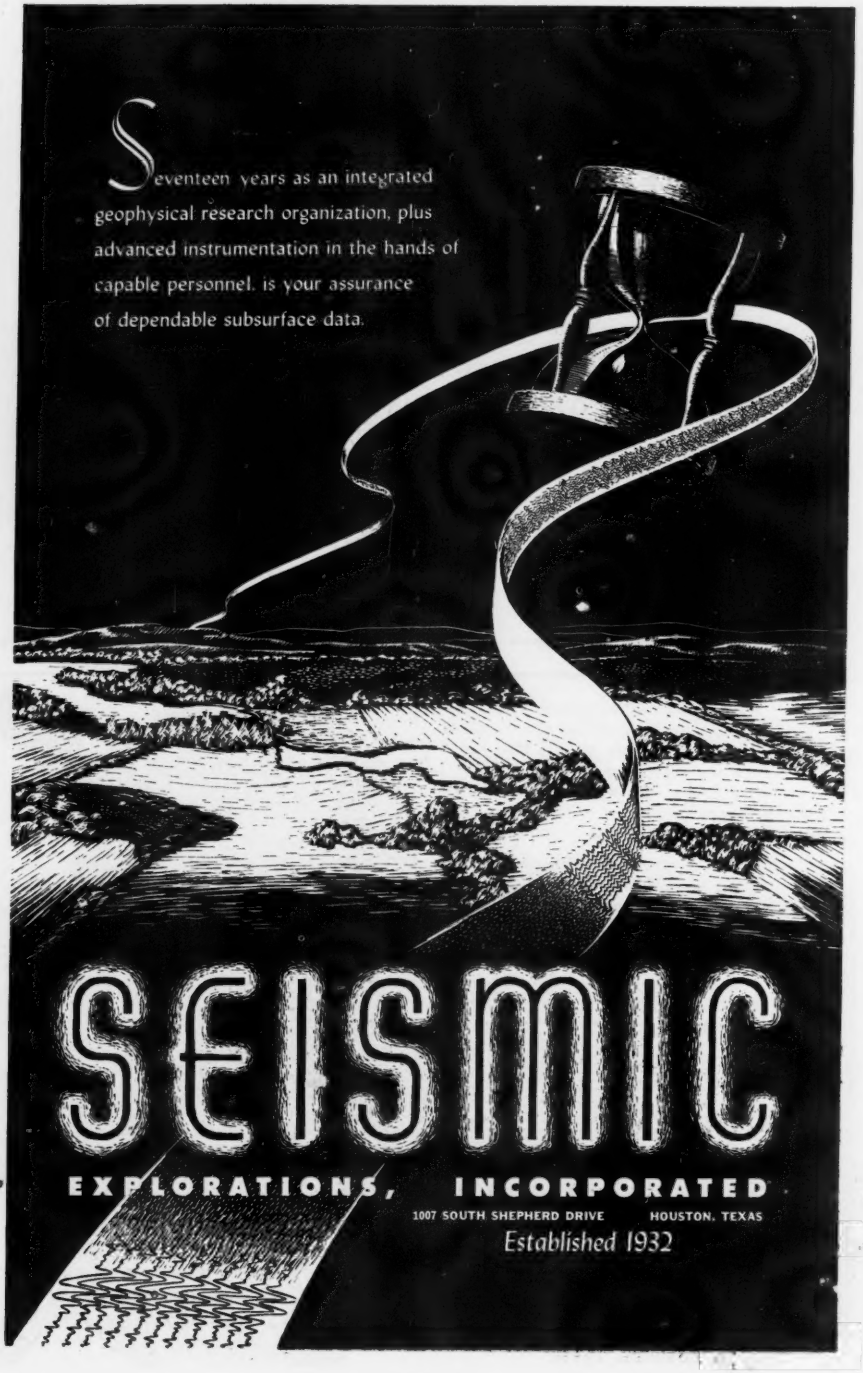
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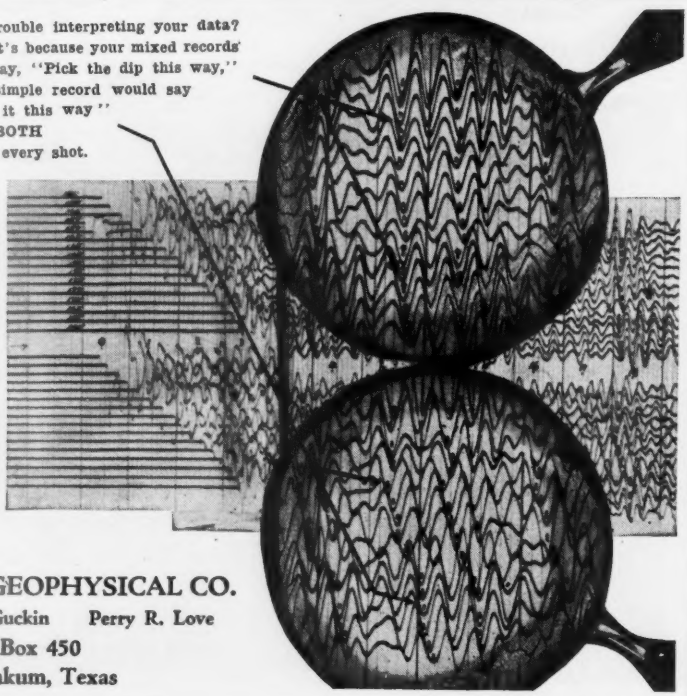

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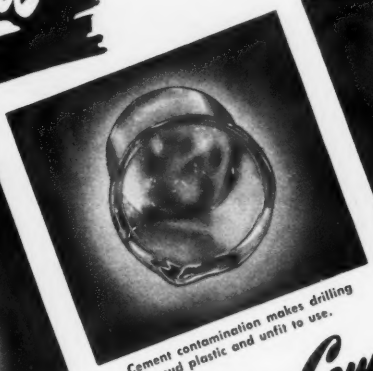

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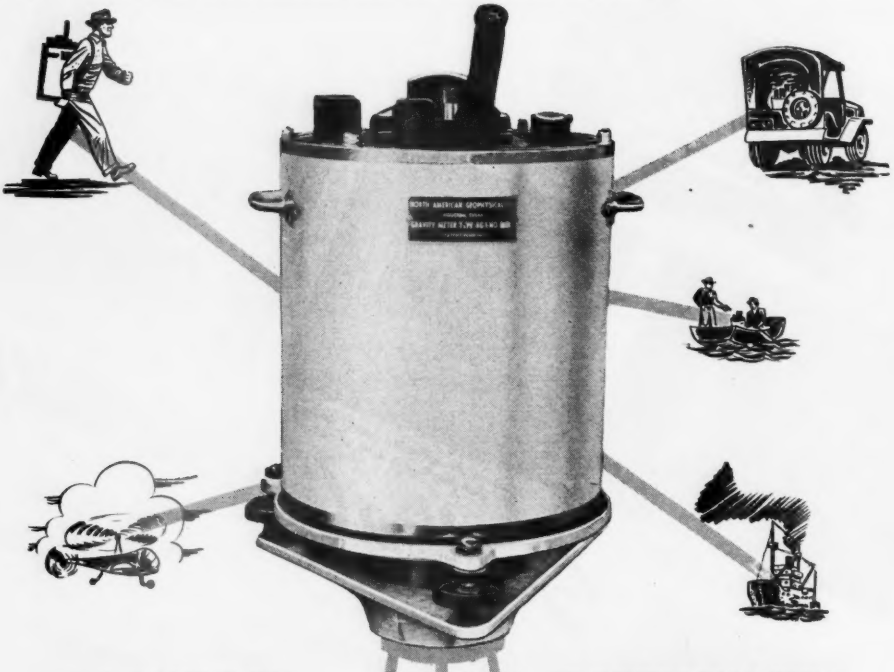

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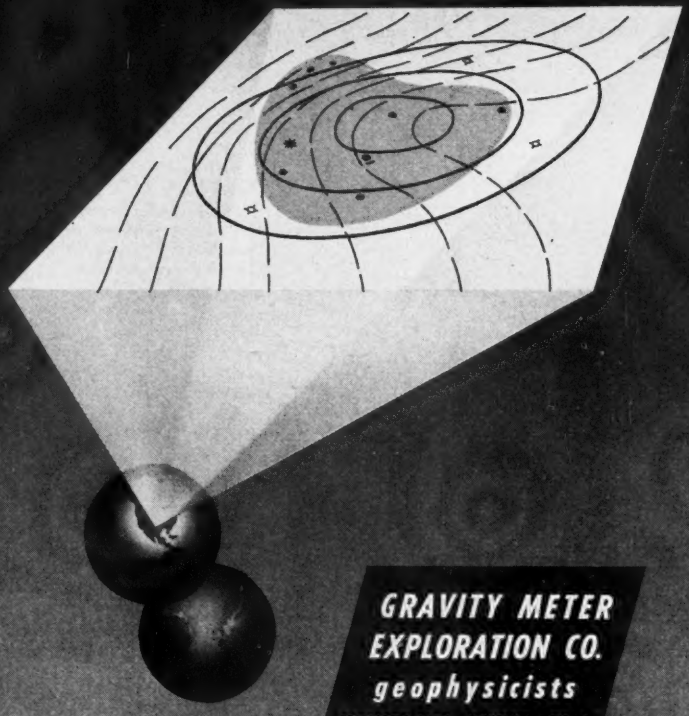

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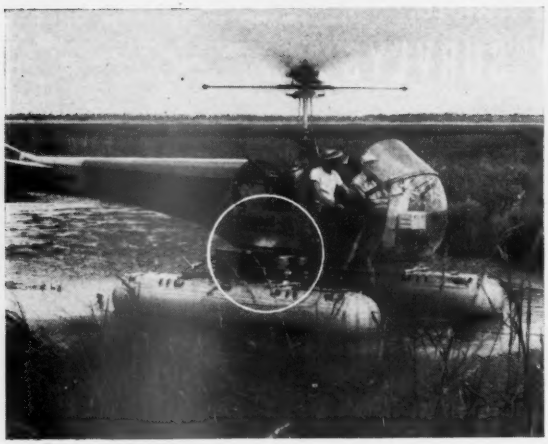

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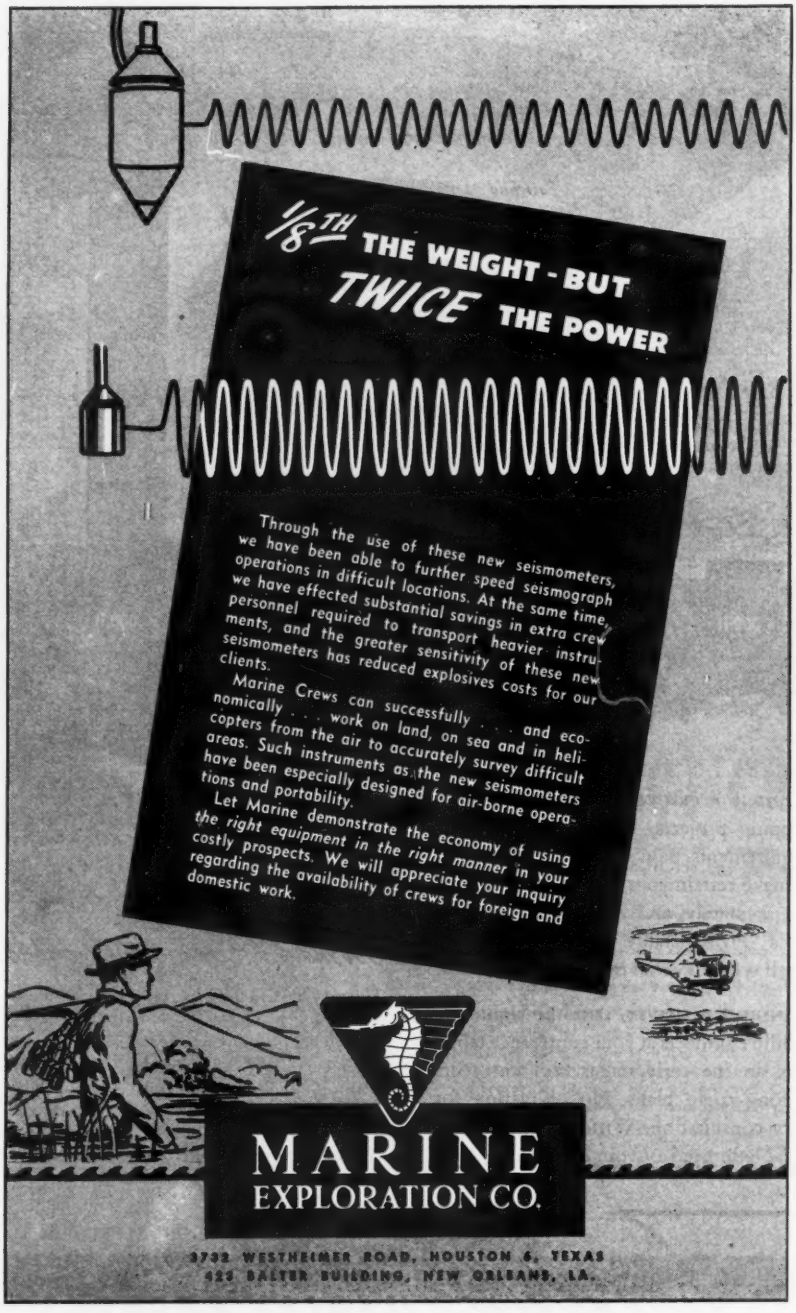
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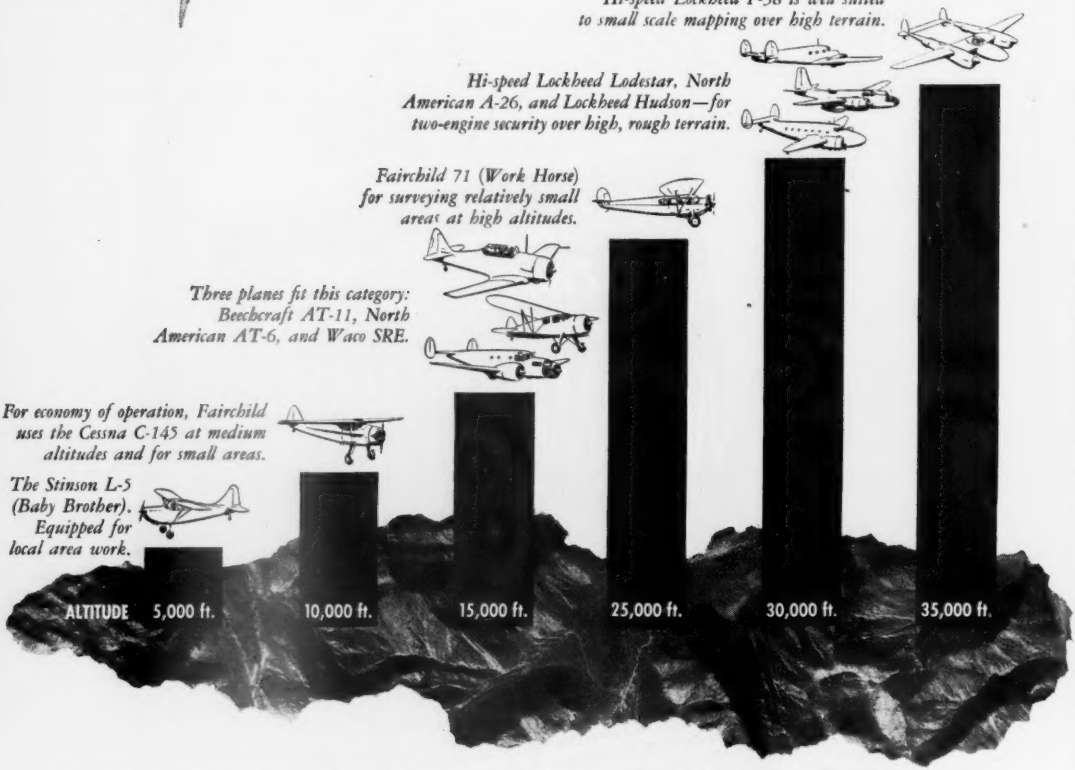
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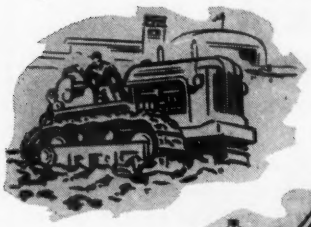

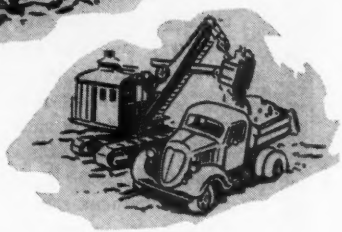

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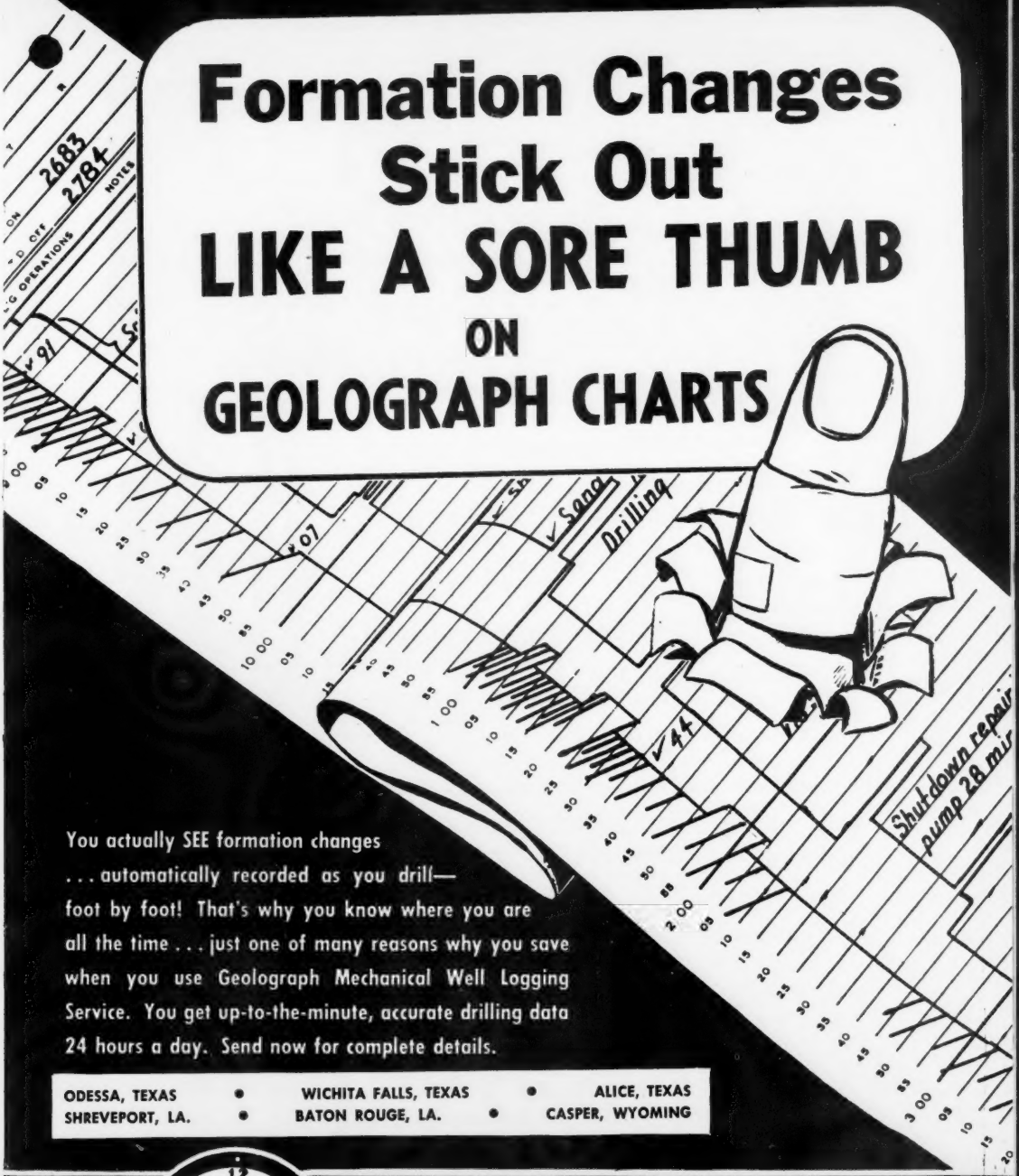

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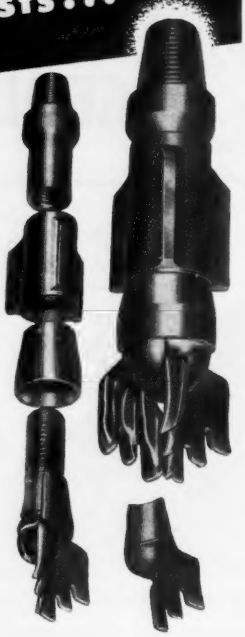

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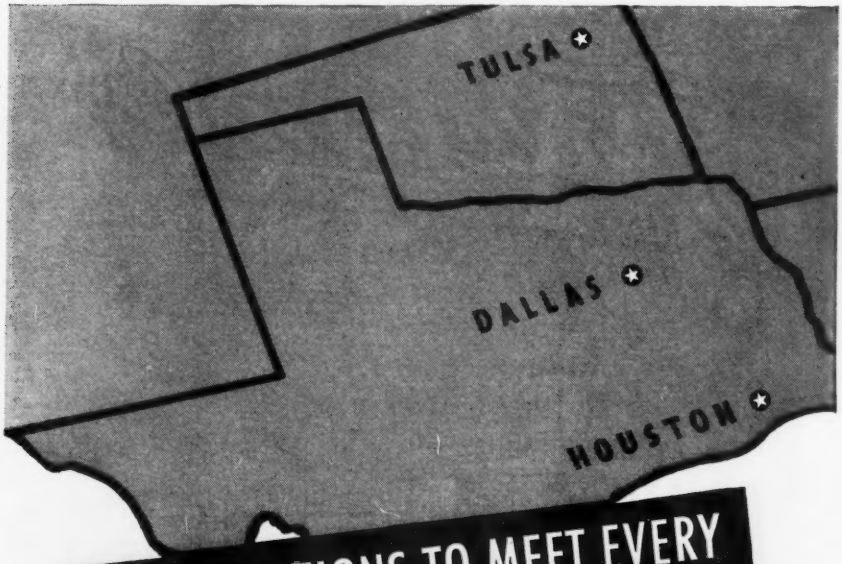

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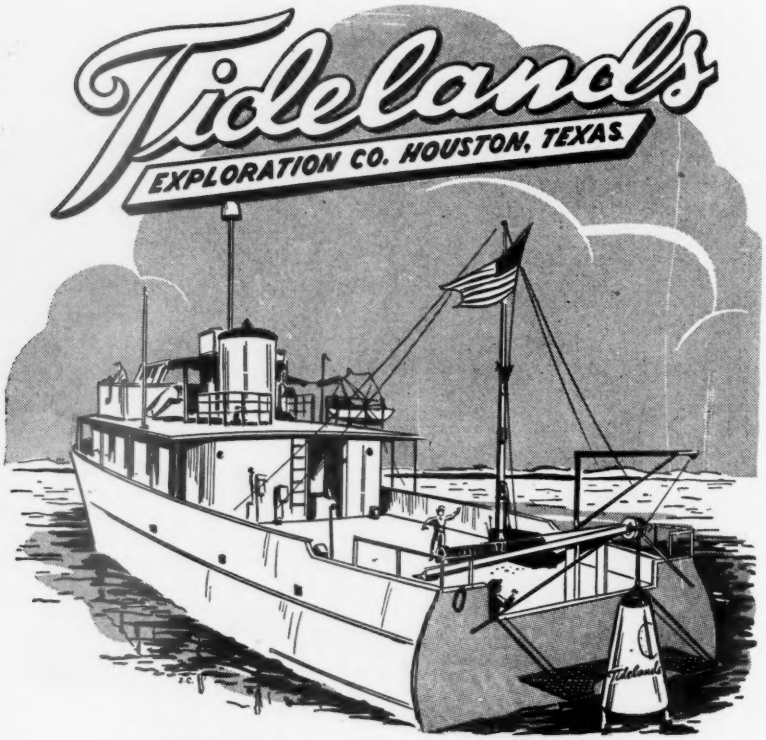

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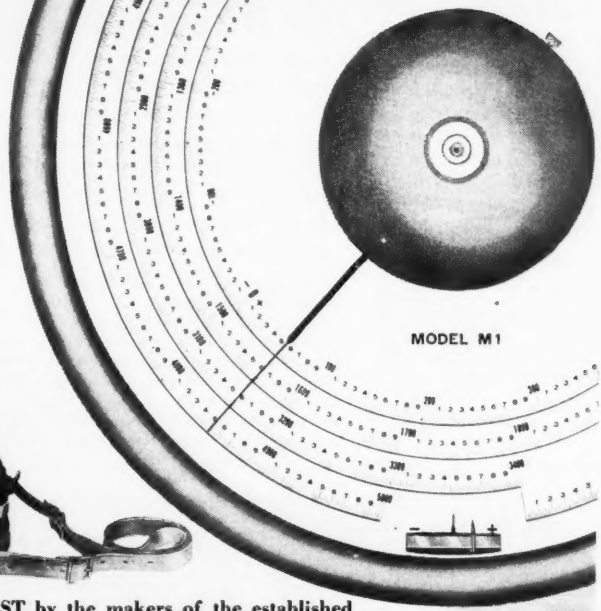

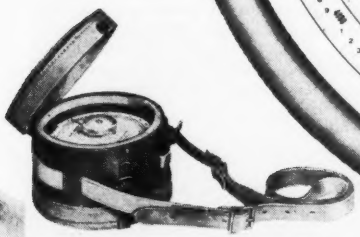

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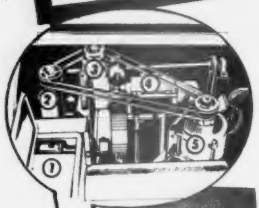

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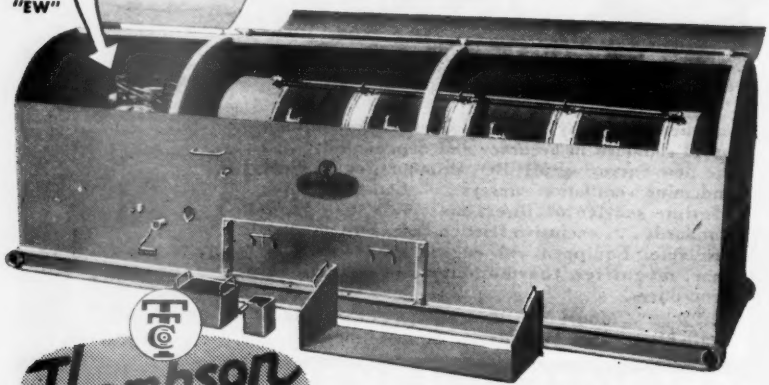

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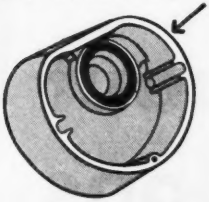

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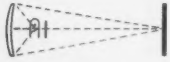

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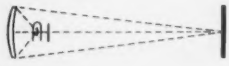

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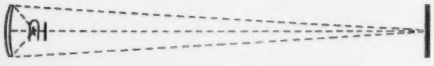

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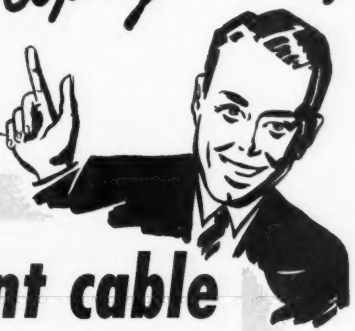

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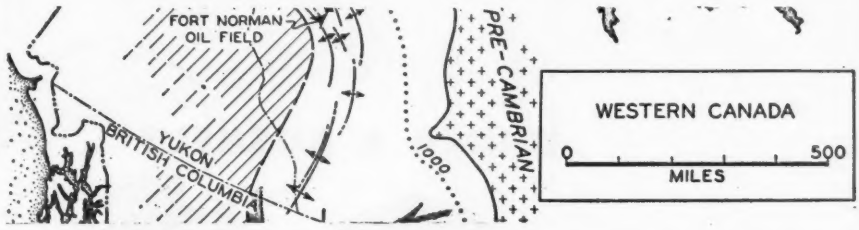

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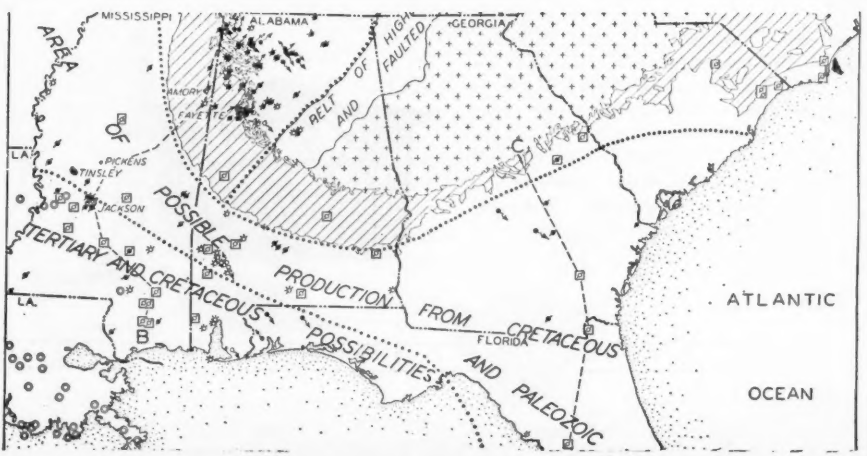

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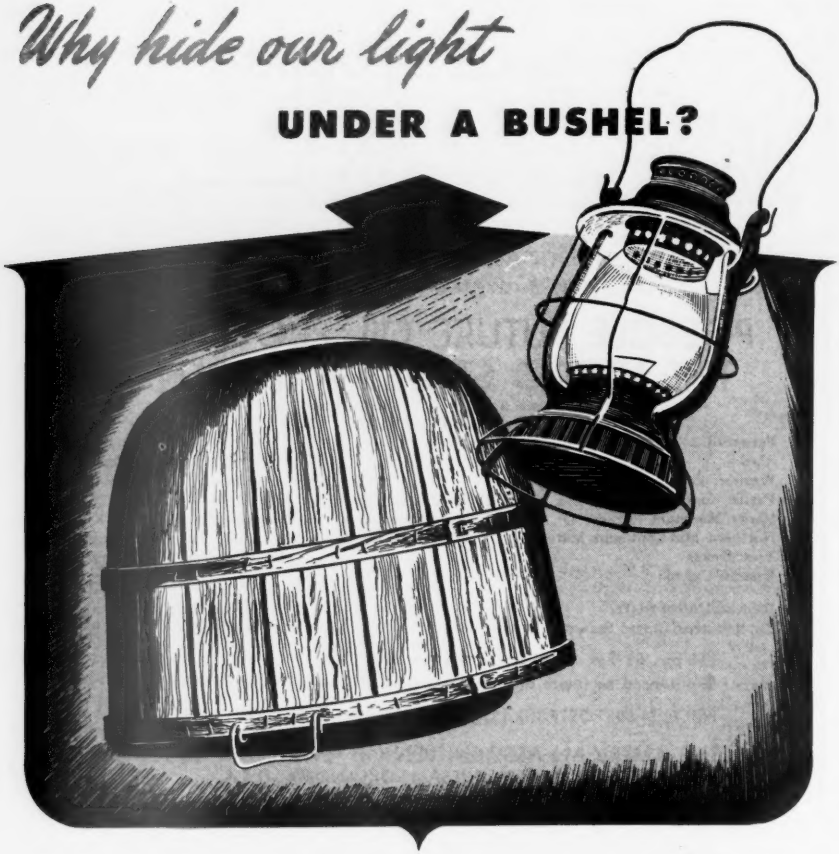

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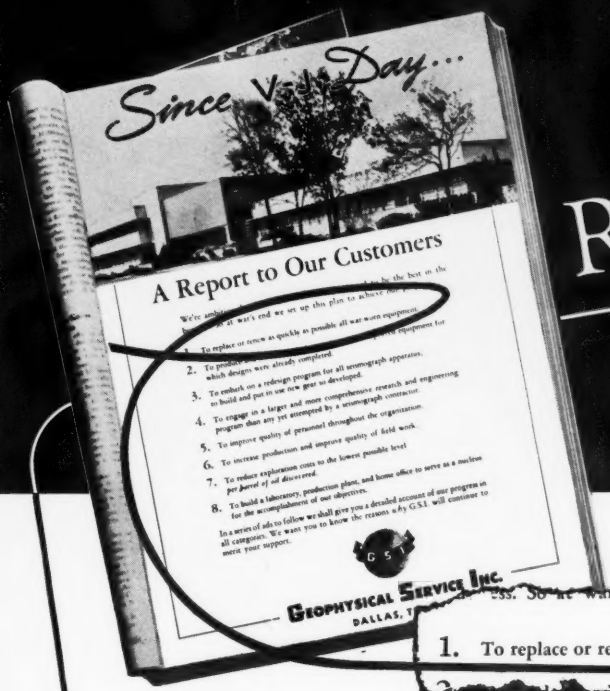
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